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SELECTION OF "WINDOW" SIZES WHEN CALCULATING FRACTAL DIMENSIONS OF AGRICULTURAL LAND SPACE IMAGES

Abstract. The quality of crop condition assessment can be influenced by the parameters of the method used to determine fractal dimensions, in particular the size of the "window". **The subject** of the study is to assess the impact of the size of the "window" on the values of fractal dimensions of satellite images. **The object** of the study is satellite images of agricultural crops at different stages of vegetation taken by the Sentinel-2 satellite. **The aim** is to assess the impact of the "window" size on the values of fractal dimensions of satellite images of agricultural land and to select the "window" size for studying the condition of agricultural crops. The following **results** were obtained. The influence of the size of the "window" involved in the construction of the field of fractal dimensions on the minimum, maximum, and average values of fractal dimensions in satellite images of agricultural land was investigated. It was found that throughout the entire growing season for a field sown with corn, as the size of the "window" increases, the minimum fractal dimensions increase, while the average and maximum fractal dimensions decrease. At the same time, in the first half of the growing season, the differences in minimum fractal dimensions with small "window" sizes (up to 24 × 24 pixels) are the largest compared to the differences in maximum and average fractal dimensions. **Conclusions.** The conducted research allows us to develop recommendations for choosing the size of the "window" and the type of fractal dimension for analyzing satellite images of agricultural land. Thus, to assess the condition of agricultural crops, it is advisable to use the minimum fractal dimensions found in images that have the greatest differences at different stages of vegetation. To ensure a compromise between the speed of image processing and the quality of crop condition assessment, it is advisable to choose small "sliding window" sizes (up to 16×16 pixels).

Keywords: crop condition assessment; satellite images; fractal dimension; selection of "window" sizes.

Introduction

Remote sensing (RS) data are currently widely used to assess the condition of agricultural land [1]. The dynamics of agricultural work require agricultural producers to quickly assess the results and quality of their work. These tasks are solved by the widespread use of space-based RSE tools, which allow for regular monitoring of agricultural land [2]. The speed of obtaining RSI data from large areas (with a frequency of 1 to 8 days) and the clarity of the results during their processing (with spatial resolution from 250 to 10 meters) allows specialists to quickly respond to changes in the condition of agricultural land [3]. Recently, there has been a trend towards increasing access to remote sensing data. Users can obtain satellite images of the areas under study from the Terra, Aqua, Landsat 8, and Sentinel-2 remote sensing satellites free of charge (they are freely available) via the Internet. For example, there is an up-to-date and constantly updated database of satellite images from the Sentinel-2 satellite [4], which allows them to be used for various tasks, including assessing the condition of agricultural land.

Many methods for assessing the condition of agricultural land and crops are based on the use of the normalized difference vegetation index (NDVI). The paper [5] presents the results of studies of changes in the NDVI index of multi-temporal satellite images of agricultural land. It should be noted that data from the near-infrared and red channels of Earth observation satellites are used to calculate the NDVI index, which complicates the acquisition and processing of the source image.

To increase the informativeness of satellite images when monitoring various surfaces, in particular the Earth's surface, methods of fractal image analysis are used [6, 7]. The possibility of applying fractal analysis of Sentinel-2 satellite images to assess the condition of agricultural crops at different stages of vegetation is shown in [8, 9]. In [8], fields sown with corn are analyzed, and in [9], fields sown with buckwheat, wheat, sunflower, and barley are analyzed. In this case, space images in one wavelength range are used. However, these works do not consider the influence of the "window" size on the values of fractal dimensions in satellite images of agricultural land. In this regard, it is advisable to consider the possibility of selecting the size of the "window" to be used when calculating the fractal dimensions of satellite images of agricultural land.

The aim of the article: to evaluate the influence of the "window" size on the values of fractal dimensions of satellite images of agricultural land and the choice of "window" size for studying the state of agricultural crops.

Characteristics of agricultural land satellite images

To study the effect of the "window" size on the fractal dimensions of satellite images of agricultural land, we will use Sentinel-2 satellite images, which are freely available on the Internet [4]. During the fractal analysis, satellite images in the near-infrared range (Sentinel-2 satellite channel b8) will be used. Channel b8, with a wavelength of 832 nm, allows us to obtain satellite images that capture the reflection of solar radiation from vegetation.

For further assessment of the condition of agricultural land and crops, a database of satellite images of the land of the Vilkhuvatskaya village council of the Chutivsky district of the Poltava region was created, most of which is cultivated by the private agricultural enterprise "Druzhba" [8]. The satellite images were obtained throughout 2018, and the images have a spatial resolution of 10 meters. A field sown with corn was selected for further study.

Fig. 1 shows elements of images of a field sown with corn, cut out from the main (large) satellite images, as of:

04.06.2018 (a), 14.06.2018 (b); 16.06.2018 (c), 21.06.2018 (d); 26.06.2018 (e); 29.06.2018 (f); 29.07.2018 (g); 05.08.2018 (h); 08.08.2018 (i); 10.08.2018 (j); 18.08.2018 (k); 23.08.2018 (l); 25.08.2018 (m).

Visual analysis of the elements of the satellite images in Fig. 1 showed that they differ in the degree of gray color (gray gradation), but the differences are not significant. Thus, in the initial phases of vegetation (early June to June 26, 2018), darker shades of gray are observed, as shown in Fig. 1, *a–d*. At the end of June (June 29, 2018), in July (July 29, 2018), and at the beginning of August (until August 18, 2018), lighter shades of gray gradations are observed (see Fig. 1, *e–j*), and at the end of August (in the final stages of vegetation), the shades of gray become darker again (see Fig. 1, *k–m*).

It should also be noted that the satellite images reveal some features of the structure of the field under study, which is planted with corn. Thus, all satellite images show the results of field cultivation in the form of stripes with slight differences in gray gradations. This slight layering spreads from the upper left corners to the lower right corners of all images.

In addition, a small light area is observed in the lower left corner of the satellite images, which is especially evident in the final stages of vegetation (see Fig. 1, *i*–*m*). Most likely, this anomalous area is due to the negative impact of weather conditions.

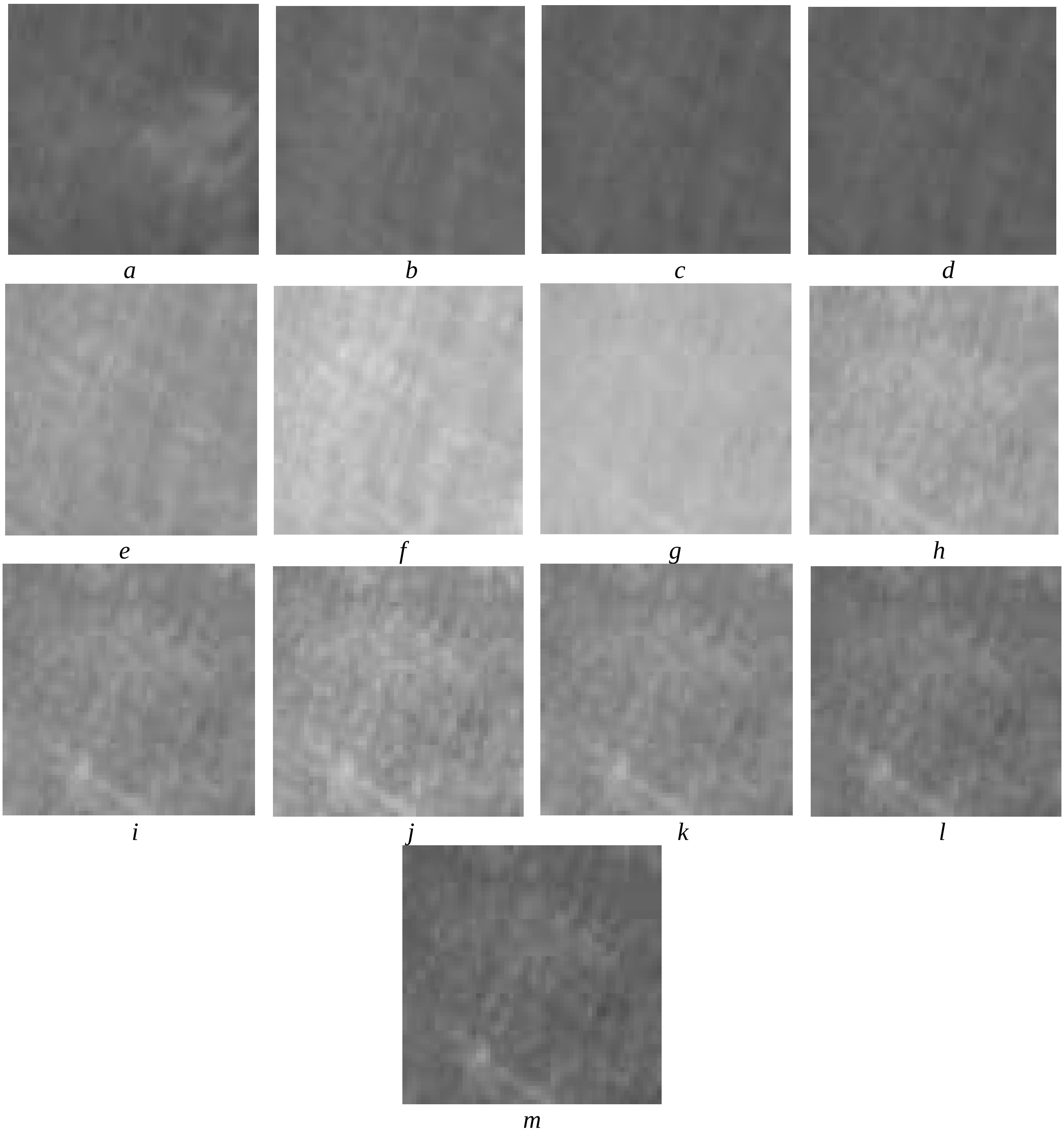

Fig. 1. Elements of space images (channel b8) of corn fields as of: June 4, 2018 (*a*), June 14, 2018 (*b*); 16.06.2018 (*c*), 21.06.2018 (*d*); 26.06.2018 (*e*); 29.06.2018 (*f*); 29.07.2018 (*g*); 05.08.2018 (*h*); 08.08.2018 (*i*); 10.08.2018 (*j*); 18.08.2018 (*k*); 23.08.2018 (*l*); 25.08.2018 (*m*)

The satellite images also show that the presence of clouds causes a change in gray gradations (a light shade appears in Fig. 1, a), and in the presence of cloud shadows, a dark shade appears.

Thus, using only visual analysis of satellite images, it is only possible to qualitatively assess changes in the condition of agricultural crops, evaluate the uniformity of crops, and the progress of field work. However, it is practically impossible to quantitatively assess the condition of agricultural crops at different stages of vegetation based on the results of visual analysis.

Let us process the satellite images of a field sown with corn, discussed above, using fractal analysis and consider the influence of the "window" size on the values of fractal dimensions.

Selecting the size of the "window" when calculating the fractal dimensions of agricultural land satellite images

The information carrier in the Sentinel-2 satellite image (channel b8) is light waves in the near-infrared range, formed by the reflection of solar radiation depending on the characteristics of the underlying surface. The light wave carries information about the object due to the fact that its various parameters change depending on the nature of the points on the underlying surface (relief). The result is a heterogeneous matrix of values of the intensity of solar radiation reflection from the Earth's surface. The size of the matrix is equal to the size of the satellite image.

During the fractal analysis of space (digital) images, the fractal dimensions are first calculated (the order of their determination is described in [10]), and then the field of fractal dimensions is constructed (the process of its construction is described in [7]).

There are many methods for calculating fractal dimensions, but in practice, the covering method [10] is most often used for analyzing digital images. This method provides the calculation of the Hausdorff–Bezikovich dimension, which is described by the expression:

$$D = \lim_{\varepsilon \to 0} \frac{\log N(\varepsilon)}{\log(1/\varepsilon)}, \qquad (1)$$

where ε – the length of the cube's side (the maximum length is equal to the size of the "window") covering the three-dimensional representation of the digital image; $N(\varepsilon)$ – the number of cubes covering the three-dimensional representation of the image.

As can be seen from expression (1), it is not possible to directly calculate the fractal dimension of a space image using this formula. The fractal dimension can be determined as follows.

At the beginning of the application of the covering method, a cube is created with a side length equal to ε pixels, and this cube covers the three-dimensional representation of the space image (set I). Next, the number of cubes with a side length of ε pixels covering the entire space image (set I) is calculated $N(\varepsilon)$. Then, $N(\varepsilon)$ is determined for several other values of the cube side ε. Such values of the cube sides can be, for example, $\varepsilon_2 = \varepsilon_1/2$, $\varepsilon_3 = \varepsilon_1/4$, $\varepsilon_4 = \varepsilon_1/8$, etc. In this way, the set of values $N(\varepsilon)$ is determined. Depending on the structure of the space image, the number of values may vary. At the final stage, a graph of the dependence of log $N(\varepsilon)$ on log $1/\varepsilon$ is constructed and its linear approximation is performed. The least squares method is most often used for approximation, which allows the calculation process to be automated.

After constructing the approximated straight line, the tangent of its slope angle is determined. This value will be the fractal dimension D of the space image.

To construct the field of fractal dimensions, the space image is scanned using a "window" of size $n \times m$ pixels, which is moved in steps of s (the "window" is "sliding" if $s = 1$, and "jumping" if $s > 1$) [7]. At each step of the "window" movement, the numerical value of the fractal dimension is calculated and recorded in the matrix $\boldsymbol{D}$. This matrix is called the "field of fractal dimensions". In this work, fractal dimension fields are constructed for elements of space images with dimensions of 56×56 pixels, and the dimensions of the "sliding window" $n \times m$ vary.

In [9], the state of agricultural crops was assessed using the minimum, maximum, and average values of fractal dimensions present in the satellite image, and it was determined that they are the most informative, but no comparative analysis was performed.

Let us consider the influence of the “window” size on the value of these fractal dimensions in satellite images of a field sown with corn. The numerical values of the minimum, maximum, and average values of fractal dimensions for different “window” sizes are given in Table 1.

Table 1. *Minimum, maximum, and average values of fractal dimensions of space images of a field sown with corn at different "window" sizes*

Date	Size of the "window" in pixels								
	4 × 4			8 × 8			16 × 16		
	D_{min}	D_{max}	D_{av}	D_{min}	D_{max}	D_{av}	D_{min}	D_{max}	D_{av}
04.06.18	2,882	2,991	2,964	2,884	2,984	2,961	2,906	2,976	2,954
14.06.18	2,923	2,993	2,970	2,939	2,989	2,968	2,951	2,981	2,967
16.06.18	2,927	2,993	2,968	2,942	2,985	2,966	2,947	2,980	2,966
21.06.18	2,927	2,995	2,971	2,935	2,987	2,969	2,940	2,982	2,967
26.06.18	2,936	2,993	2,974	2,944	2,987	2,973	2,947	2,983	2,970
29.06.18	2,932	2,994	2,972	2,938	2,990	2,971	2,942	2,984	2,970
29.07.18	2,950	2,995	2,981	2,960	2,990	2,979	2,967	2,987	2,979
05.08.18	2,913	2,992	2,967	2,931	2,994	2,965	2,940	2,976	2,965
08.08.18	2,904	2,991	2,964	2,925	2,985	2,962	2,936	2,978	2,962
10.08.18	2,875	2,985	2,948	2,893	2,972	2,946	2,903	2,967	2,944
18.08.18	2,860	2,991	2,953	2,882	2,978	2,949	2,900	2,967	2,946
23.08.18	2,844	2,986	2,948	2,860	2,976	2,943	2,881	2,964	2,937
25.08.18	2,814	2,986	2,944	2,837	2,978	2,938	2,863	2,961	2,929
	24 × 24			32 × 32			48 × 48		
04.06.18	2,920	2,972	2,947	2,932	2,948	2,940	2,942	2,943	2,943
14.06.18	2,959	2,975	2,966	2,960	2,973	2,965	2,964	2,966	2,965
16.06.18	2,958	2,977	2,966	2,959	2,972	2,964	2,964	2,965	2,965
21.06.18	2,956	2,979	2,966	2,957	2,975	2,963	2,961	2,962	2,962
26.06.18	2,958	2,980	2,969	2,958	2,978	2,966	2,966	2,968	2,967
29.06.18	2,956	2,983	2,969	2,962	2,977	2,967	2,966	2,968	2,967
29.07.18	2,966	2,986	2,980	2,969	2,984	2,980	2,974	2,977	2,975
05.08.18	2,947	2,976	2,967	2,951	2,975	2,966	2,955	2,957	2,956
08.08.18	2,944	2,973	2,963	2,948	2,970	2,962	2,952	2,955	2,953
10.08.18	2,913	2,959	2,942	2,920	2,953	2,939	2,927	2,930	2,928
18.08.18	2,911	2,961	2,946	2,919	2,959	2,944	2,926	2,929	2,927
23.08.18	2,894	2,957	2,935	2,902	2,948	2,931	2,911	2,914	2,912
25.08.18	2,878	2,954	2,926	2,888	2,941	2,922	2,898	2,901	2,899

In [8], it was shown that throughout the entire vegetation period, the average values of fractal dimensions first increase and then decrease to minimum values. The same pattern of change is observed for NDVI indices. Table 1 shows that the minimum and maximum fractal dimensions undergo the same changes.

As can be seen from the data in Table 1, throughout the entire vegetation period for a field sown with corn, as the size of the "window" increases, the minimum fractal dimensions increase, while the average and maximum fractal dimensions decrease. At the same time, in the initial and final phases of vegetation, the increase (decrease) in fractal dimensions is greater than in the middle phase of vegetation.

For example, the minimum fractal dimensions increase by an average of 0.010 until June 16, 2018, by 0.005 from June 16, 2018, to July 29, 2018, and by 0.020 after July 29, 2018. For average and maximum fractal dimensions, approximately the same decrease in values is observed for the specified dates.

Table 1 also shows that the maximum fractal dimensions for small "window" sizes remain virtually unchanged (change in the third decimal place for "window" of 4 × 4 and 8 × 8 pixels) throughout the entire vegetation period, for larger "window" sizes, differences in maximum fractal dimensions are observed in the second decimal place. The opposite trend is observed for minimum fractal dimensions. For small window sizes, the values of the minimum fractal dimensions change in the second decimal place throughout the entire vegetation period, and for large window sizes, they change in the third decimal place.

Changes in average fractal dimensions depend to a lesser extent on the size of the "window" throughout the entire vegetation period, and differences for all "window" sizes are manifested in the second decimal place. At the same time, for small sizes of space images, for example, such as 56 × 56 pixels, it is advisable to select a "window" with a size of 4 × 4 pixels and a movement step equal to one, i.e., to select a "sliding window". Choosing a "window" of this size also allows you to more confidently identify anomalous areas in the images.

Let's consider how much the minimum, maximum, and average fractal dimensions change when the "window" size increases. Fig. 2 shows graphs of changes in these fractal dimensions between two dates: between 04.06.2018 and 29.07.2018 (*a*), between 29.07.2018 and 25.08.2018 (*b*), i.e., in the first and second half of the growing season.

In Fig. 2, the dimensions of the "window" are plotted on the x-axis, so $w = 4 = 4 \times 4$, $w = 8 = 8 \times 8$, $w = 16 = 16 \times 16$, etc., and the y-axis shows the difference between the minimum (dashed line), maximum (dotted line), and average (solid line) fractal dimensions (ΔD).

As can be seen in Fig. 2, *a*, in the first half of the growing season, the differences between the minimum fractal dimensions (dashed line) are the largest compared to the differences between the maximum (dotted line) and average (solid line) fractal dimensions. With larger "window" sizes, these differences in fractal dimensions do not differ, i.e., they have the same value.

It should be noted that as the "window" size increases, the differences in minimum fractal dimensions decrease, while the differences in maximum and average dimensions increase.

Fig. 2, *b* shows that in the second half of the growing season, the nature of changes in the minimum (dashed line), maximum (dotted line), and average (solid line) fractal dimensions is practically the same as in the first half of the growing season.

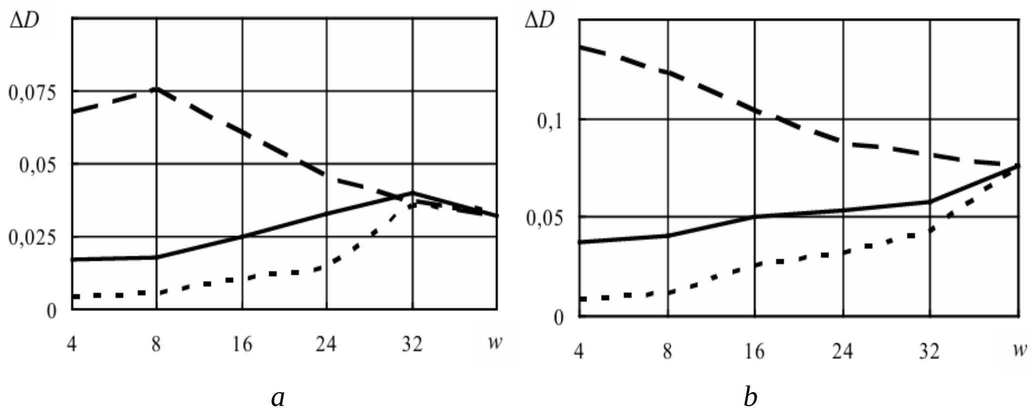

Fig. 2. Dependence of the differences between the minimum, maximum, and average fractal dimensions in a space image of a field sown with kukuaudza on the size of the "window": between June 4, 2018, and July 29, 2018 (*a*), between July 29, 2018, and August 25, 2018 (*b*)

A slight difference is that these differences in fractal dimensions become the same at a "window" size of 48 × 48 pixels.

Thus, the studies conducted allow us to develop recommendations for selecting the size of the "window" and the type of fractal dimension for analyzing satellite images of agricultural land. So, to assess the condition of agricultural crops, it is advisable to use the minimum fractal dimensions found in images that have the greatest differences at different stages of vegetation. It is advisable to select window sizes up to 24 × 24 pixels.

It should also be noted that the use of large windows leads to an increase in the calculation time of fractal dimensions within the window, which in turn leads to an increase in the time required to construct the fractal dimension field. Therefore, to ensure a compromise between the speed of image processing and the quality of agricultural land assessment, it is advisable to choose small "sliding window" sizes (up to 16×16 pixels).

Conclusions

The dynamics of agricultural work requires agricultural producers to quickly assess their results and the quality of their work. These tasks are solved through the widespread use of RS space tools, which allow for regular monitoring of agricultural land.

To increase the informativeness of satellite images during the monitoring of various surfaces, in particular the Earth's surface, methods of fractal image analysis are used, which involve the construction of their fractal dimension fields. In this case, satellite images in a single wavelength range are used.

The influence of the size of the "window" involved in the construction of the field of fractal dimensions on the minimum, maximum, and average values of fractal dimensions in satellite images of agricultural land has been studied. It has been established that throughout the entire vegetation period for a field sown with corn, as the size of the "window" increases, the minimum fractal dimensions increase, while the average and maximum fractal dimensions decrease. At the same time, in the first half of the growing season, the differences in minimum fractal dimensions with small "window" sizes (up to 24 × 24 pixels) are the largest compared to the differences in maximum and average fractal dimensions.

The studies conducted allow us to develop recommendations for selecting the size of the "window" and the type of fractal dimension for analyzing satellite images of agricultural land. Thus, to assess the condition of agricultural crops, it is advisable to use the minimum fractal dimensions found in images that have the greatest differences at different stages of vegetation. To ensure a compromise between the speed of image processing and the quality of crop condition assessment, it is advisable to choose small "sliding window" sizes (up to 16×16 pixels).

In further research, it is advisable to evaluate the possibility of using fractal analysis to determine the size of field areas where agricultural work is carried out using "windows" of different sizes.

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ВИБІР РОЗМІРІВ "ВІКНА" В ПРОЦЕСІ РОЗРАХУНКУ ФРАКТАЛЬНИХ РОЗМІРНОСТЕЙ КОСМІЧНИХ ЗНІМКІВ СІЛЬСЬКОГОСПОДАРСЬКИХ ЗЕМЕЛЬ

На якість оцінювання стану сільськогосподарських культур можуть впливати параметри методу визначення фрактальних розмірностей, зокрема розмірів "вікна". **Предмет дослідження** – оцінювання впливу розмірів "вікна" на величини фрактальних розмірностей космічних знімків. **Об'єктом дослідження** є космічні знімки супутника Sentinel-2 сільськогосподарських культур на різних фазах вегетації. **Мета роботи –** оцінити вплив розмірів "вікна" на величини фрактальних розмірностей космічних знімків сільськогосподарських земель і вибору розмірів "вікна" для аналізу стану сільськогосподарських культур. **Досягнуті результати**. Досліджено вплив розмірів "вікна", яке бере участь у побудові поля фрактальних розмірностей, на величини мінімальних, максимальних і середніх значень фрактальних розмірностей, що є на космічних знімках сільськогосподарських земель. Установлено, що впродовж усього процесу вегетації для поля, засіяного кукурудзою, внаслідок збільшення розмірів "вікна" мінімальні фрактальні розмірності збільшуються, а середні й максимальні – зменшуються. Крім того, у першій половині періоду вегетації різниці мінімальних фрактальних розмірностей за незначних розмірів "вікна" (до 24 × 24 пікселів) найбільші, якщо порівнювати з різницями максимальних і середніх фрактальних розмірностей. **Висновки**. Результати дослідження дають змогу розробити рекомендації щодо вибору розмірів "вікна" й типу фрактальної розмірності для аналізу космічних знімків сільськогосподарських земель. Так, для оцінювання стану сільськогосподарських культур доцільно використовувати мінімальні фрактальні розмірності, що є на знімках, які мають найбільші розбіжності на різних етапах вегетації. Для забезпечення компромісу між швидкістю оброблення знімків та якістю оцінювання стану сільськогосподарських культур доречно обирати невеликі розміри "ковзного вікна" (до 16×16 пікселів).

Ключові слова: оцінювання стану сільськогосподарських культур; космічні знімки; фрактальна розмірність; вибір розмірів "вікна".

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