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APPLICATION OF MATHEMATICAL MORPHOLOGY METHODS IN TERMS OF EROSIVE PROCESSES RESEARCH USING AERIAL PHOTOGRAPHY MATERIALS

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Object of study. Planned distribution establishment of erosive “spots” of the agricultural lands is based on the processing of binary images of aerial photographic materials using morphological and planimetric methods of analysis. **Methodology**. Offered methodology is based on the non-linear operators’ application. These operators are mathematically described by the theoretical and set formalism. Mathematical morphology uses two main morphological filters which can be represented as a successive combination of two stages of image analysis on the basis of the morphological operators using: constriction and extending. **Results.** For obtaining maximal image characteristics it was suggested to carry out processing in the following sequence: binarization, segmentation, and morphological and planimetric definitions. Binarization content is characterized by bright spots, which show the release of soil-forming rocks to the surface, which can be divided by well-known method of prof. V. M. Sokolova (with sequential split pixels). The above-mentioned process is mostly used in digital photogrammetry. The corresponding mathematical apparatus is represented. The next stage of binary image processing is the allocation of adjacent boundaries and sites by the Laplace’s method of segmentation. In such a case, an estimation of two different contrast areas A and B is conducted. To determine the boundaries of their division, the marks of the contrast ratio’s second derivative are estimated. It is offered to carry out segmentation according to graph theory. An illustration of this segmentation is represented graphically. At the third stage of the study, morphological and planimetric determinations were performed on the investigated image using 2 × 2 pixel masks. As a result, it is possible to calculate statistical distributions of spots on aerial photographs by area, perimeter, and factor form. **Scientific novelty**. The offered method of step-by-step processing of aerial photography is based on the use of binary and segmentation methods which allow acquiring a precise image and more accurate results of morphological and planimetric definitions. **Practical significance.** According to the above-mentioned algorithm, some morphometric characteristics of spots on aerial photographs were analyzed: area, perimeter, and form factor. Application examples which confirm the universality of the suggested method for analyzing images in a microphotogrammetry are given in the work [Melnyk, 2013].

Key words: aerial photography, segmentation, pixel mask, binarization, erosion, morphological filters.

Introduction

In modern erosion studies considerable attention is paid to the use of cosmic and aerial photography for the ablation intensity study. At the same time, the largest number of studies are related to the establishment of the spatial location of degradaded parts of agricultural lands on the basis of the analysis of various spectral or panchromatic photos [Zamiatin A. V., Zhang, Y., 2004; Protsyk M. T., 2012]. The result of the satellite images processing was a synthesized image showing the changes that took place in the agro-landscape under the influence of anthropogenic and natural components of degradation. An example of such a work is labor [Protsyk M. T., 2012; Salnikov I. I., 2013]. Not less interesting is the use of binary images [Tumskaia O. V., 2004] for analyzing the erosion process dynamics.

A mathematical apparatus in such studies is the morphological analysis of images, which is based on digital algorithm processing [Vizilter Yu. V., 2009; Melnyk V. M., 2009; Rosenfeld A., 1972; Sergeev V., 1984]. An urgent and important task is the use of several methods of analysis with the aim of their operational comparison and a level of reliable results.

Object

Establishment of the planned distribution of erosion “spots” of agricultural lands is based on the processing of binary images of aerial photographs using morphological and planimetric analysis methods. The key principles of the application use mathematical morphology methods.

Methodology

The methods of digital images processing using mathematical morphology was offered in the works

[Serra J., 1992; Shostak A. V., 2011]. This technique is based on the application of nonlinear operators, which are mathematically described by the set and theoretical formalism. Mathematical morphology uses two basic morphological filters that can be represented as sequential combinations of two stages of image analysis based on the use of two basic morphological operators: constriction and expansion. For example, using a group of translation glidings (landslides), one can set the morphological opening of the image A by the structured elements B:

$$O(A,B)=\cup_{\langle x,y\rangle}\{B(x,y):B(x,y)\}\le A, \qquad (1)$$

where $B(x,y)$ – image B which has a landslide on the vector $\langle x,y\rangle$.

You can verify that (1) is a morphological projector:

$$O(A,B)=O(O(A,B),B). \qquad (2)$$

Such an operator is invariant according to landslides. In addition, this operator is monotonous in the sense that:

$$\forall A,B=O(A,B)\le A. \qquad (3)$$

For obtaining reliable results it is necessary to have an image with clear contours of the investigated objects. In terms of the afore-mentioned, it is offered to process the aerial photographs in the following sequence: binarization, segmentation, morphological, and planimetric determination. Let us consider in detail their content.

1. Images binarization

To obtain the parameters of erosion "spots" for their aerial photographs, it is necessary to implement the binarization process. Such a process is mostly used in digital photogrammetry [Dorozhynsky O., 2008] and in the process of analyzing images for different purposes [Molchanova V. S., 2015; Sauvola J., 2000; Yang Y., 2010; Pratikakis I., 2013].

Mathematical binarization is carried out according to the following scheme [Sokolov V. N., 1997]:

$$\begin{pmatrix}0&0\\0&0\end{pmatrix}\to SQ_0;$$

$$\begin{pmatrix}0&0\\0&1\end{pmatrix}\cdot\begin{pmatrix}0&0\\1&0\end{pmatrix}\cdot\begin{pmatrix}1&0\\0&0\end{pmatrix}\cdot\begin{pmatrix}0&1\\0&0\end{pmatrix}\to SQ_1$$

$$\begin{pmatrix}0&1\\0&1\end{pmatrix}\cdot\begin{pmatrix}1&1\\0&0\end{pmatrix}\cdot\begin{pmatrix}1&0\\1&0\end{pmatrix}\cdot\begin{pmatrix}0&0\\1&1\end{pmatrix}\to SQ_2$$

$$\begin{pmatrix}1&1\\0&1\end{pmatrix}\cdot\begin{pmatrix}1&1\\1&0\end{pmatrix}\cdot\begin{pmatrix}0&1\\1&1\end{pmatrix}\cdot\begin{pmatrix}1&0\\1&1\end{pmatrix}\to SQ_3$$

$$\begin{pmatrix}1&1\\1&1\end{pmatrix}\to SQ_4$$

$$\begin{pmatrix}1&0\\0&1\end{pmatrix}\cdot\begin{pmatrix}0&1\\1&0\end{pmatrix}\to SQ_5 \qquad (4)$$

where 1 – pixel that belongs to the investigated area (spot); 0 – pixel that does not belong to the "spot"; SQ_n – group of isolated points of the investigated object. Such an algorithm was partially implemented in the "Stiman" software product and required an estimation of accuracy.

The next stage of binary image processing is the separation of adjacent boundaries and segments using the Laplace's method.

2. Images segmentation

Today we know about a significant quantity of methods of digital images segmentation [Sokolov V. N., 1997; Marchukov V. S., 2011; Fowlkes C., 2003; Navon E., 2012]. Assume that two different in contrast areas A and B are estimated. To determine the boundaries of their division, marks of the second derivative of the contrast difference are estimated. This process is described in detail in relevant reference books on applied mathematics.

It is offered to carry out segmentation according to the theory of graphs [Sokolov V. N., 2002]. The algorithm is as follows. Let one vertex of the graph C_A correspond to the area A. In the case where the areas A and B have a common boundary, the corresponding vertices C_A and C_B are connected by a single edge. The directions of the edges are carried out according to the scheme, so in the areas A and B, the second derivative is in the direction perpendicular to their common boundary and is directed from A to B, and changes the sign from negative to positive. Then the edge is directed from the vertex of the graph C_A to the vertex C_B and vice versa. An example of such segmentation is illustrated in Fig. 1

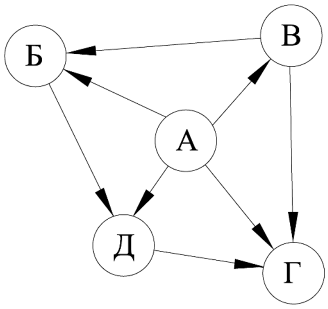


Fig. 1. Graphical represantation of the segmentation algorythm

An important point in studying the process of choosing the optimal discrimination threshold is the use of its several variants. We know a great number of global and local threshold definitions. These include P-cell method, mode method, gradient relaxation method, Ostu method, Kapoor, Sahu, Wong, Chow, Kaneko, Fernando, and Monroe. All these methods show the invariance of the threshold discrimination process. The simple method of selecting a threshold separation criterion (T) is simple in implementation and no less effective in the result. It is determined by the following formula [Cybernetic Sbornik, 1990]:

$$T=\left(f_{\min}^{0}+f_{\max}^{1}\right)/2, \qquad (5)$$

where 0 is an object, 1 is the background. This approach can be used for the final division of individual sections of the image, and if necessary, to convert the image into a binary form.

For the purpose of more in-depth analysis of the erosive state of arable land, one can represent the connection between the elements of the graph (the edge and the vertex) in the form of an incidence matrix. It is necessary to study the factors and the object, which they affect, as a graph system. Let: $[A,B,C,...]$ – agricultural parcels (land plots); $[\varGamma_1,\varGamma_2,\varGamma_3,...]$ – types of soils; $[\varPhi_1,\varPhi_2,\varPhi_3,...]$ – varieties of agrofones, $[I_1,I_2,I_3,...]$ – anti-erosion engineering structures.

Hence, the typical incidence matrix for a particular plot and types of soils will look like:

$$M_{A,\varGamma}=\begin{bmatrix} 1 & 0 & .... & 0 \\ -1 & 1 & .... & 0 \\ 0 & 0 & .... & 1 \\ 0 & 0 & .... & 0 \end{bmatrix} \qquad (6)$$

Similarly, the matrix of incidence for other factors is composed. This approach allows us to optimize the agro structure of the erosion state of arable land in the form of corresponding simplexes.

3. Mathematical and morphological determinations of planimetric characteristics

Upon completion of the segmentation of the areas, morphological and planimetric determinations are carried out on the investigated images. In the works of [Serra J., 1992; Kendall M., 1987] are given without proof from the position of the theory of geometric probability of the following formulas:

$$\begin{aligned} A(area)=1/8n(SQ_1)+1/4n(SQ_2)+\\ 7/8n(SQ_3)+n(SQ_4)+1/4n(SQ_5); \end{aligned} \qquad (7)$$

$$P=n(SQ_2)+1/\sqrt{2}\left[n(SQ_1)+n(SQ_3)\right]; \qquad (8)$$

$$E=1/4n(SQ_1)-1/4n(SQ_3)+;1/2n(SQ_5) \qquad (9)$$

Here SQ_1, $SQ_2,\ldots$, SQ_5 – pixel masks 2 × 2; n – the number of pixels.

According to these formulas it is possible to calculate statistical distributions of erosive “spots” by area, perimeter, and form factor. Examples of the universality of the offered method, as well as the corresponding calculations, were given in the work [Melnyk V., 2013] during the processing of REM images of the soil samples surface.

Accuracy of mathematical and morphological planimetric definitions. Quantitative information is obtained at discrete points in the case of a constant step along rows and between them. To estimate accuracy, one can use the well-known geometric probability theory of the problem of covering flat grooves [Kendall M., 1987].

We set the stipulation that a regular grid is applied to the investigated circuit. The number of points placed in this contour will vary, but their initial number will be repeated each time the grid is displaced so that its new points will exactly coincide with the previous position. That means that the number of points within the contour is a periodic function that can be expanded into a Fourier series [Melnyk V., 2009].

Let the lines of the raster grid be parallel to axis x. Perform the separation of the investigated contour Z of the image relative to the axis y on the same strips of width l. Expressing the number of stripes n on the basis of the Buffon task through the perimeter of the contour $p = p nl$, we obtain:

$$s_z^2 = \frac{b^2 lp}{6p} \quad (10)$$

Then the a priori accuracy of determining the area of the complex contour is the following: with the number of lines of the raster (N) – 128, the thickness of the raster (b) is 0.783; by (N) -256, (b) -387, (N) -512, (b) -0.198.

From the above-mentioned calculations it follows that the accuracy of the measurements depends essentially on the number of expansion lines, as well as on the orientation of the studied sections on the lines of the raster scan.

Results

As a test sample, a binary image was investigated (Fig. 2a). That, above all, was due to the fact that for characteristic of such an image, it was necessary to analyze only two areas of color that differ clearly.

Aerial photo scanning was performed on the photogrammetric scanner Delta-2 with a resolution of 1200 dpi with 256 gray tone levels. At the same time, the parameters of aerial photography were not taken into account, regarding the purpose of the article, which consisted only of the possibility of using the method of operative study of agricultural soil by binary images. The choice of the threshold of the maximum discrimination of a binary image from which the validity of the data actually depends on the offered threshold criterion T (5). This threshold method allowed setting the optimal level of gray (85), after which the image was translated into binary form.

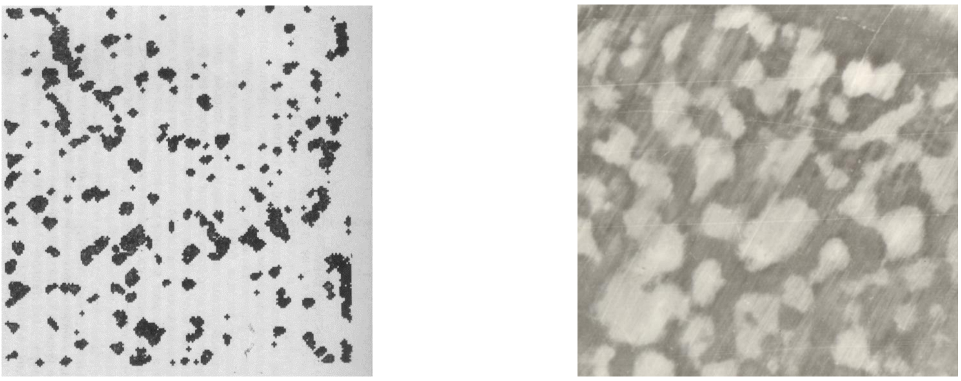
Accordingly, this material has been processed in two ways using the instrumental method PP "Surfer 7" and the offered automatic method for determining the characteristics of the objects shown in the program "Stiman".

The algorithm of work. For instrumental image processing, manual digitization of "spots" into "Surfer 7" was performed. It turned out to be a labor-intensive task; the total amount of time spent on such an approach was 2 hours 25 minutes. Accordingly, the area and perimeter were obtained.

For analysis using the "Stiman" program, the test object was scanned at four levels of bit detail, with different resolutions (300, 600, 900, and 1200 dpi).

The practical calculations confirmed Kotelnikov's theorem on the accuracy of the signal restoration in its discrete way: increasing the number of pixels per inch increases the accuracy of the resulting calculations. At the same time, the optimal work file is an image with a resolution of 900 dpi. Table 1 shows the a posteriori calculation of the accuracy of such a procedure. The time spent processing one image was 11 minutes.

As a result of the test object processing, it has been found that the optimal characteristics for the research of the images are as follows: the resolution of 900 dpi, the threshold limit discrimination of binary image (gray level) – 85. The deviation of manual and automatic processing was 4 %, while processing and obtaining results using Stiman was 13 times more efficient than in the case of instrumental execution.



a *b*

Fig. 2. Parts of the scanned test material:
a – test sample, b – fragment of aerial photography

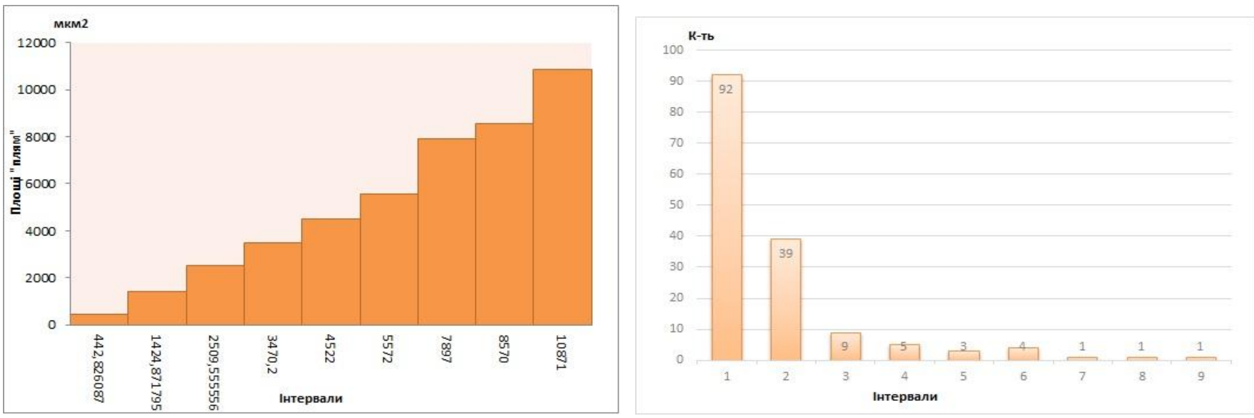
Approbation of the suggested approach. Fig. 2, b shows a fragment of the aerial photography of the field area subjected to water erosion in the territory of the Vilhiv Village, Council of Gorohiv District, Volyn Region. Using the suggested method, an analysis of the correspon-ding image was carried out, the result of which was the construction of a series of histograms (Fig. 3, a, b, Fig. 4, a, b, Fig. 5a, b), characterizing the morpho-logy of the objects under study (area, perimeter, form factor of stains).

Conducting automatic pixel counting, we found that 38.7 % of the aerial image covers an area exposed to water erosion. The part of the aeronautical image covering this territory is an area of 2.4520 hectares, of which: 0.9489 hectares has different degrees of erosion (weak – 0.3013 hectares, average – 0.1246 hectares, strong – 0.5230 hectares).

Table

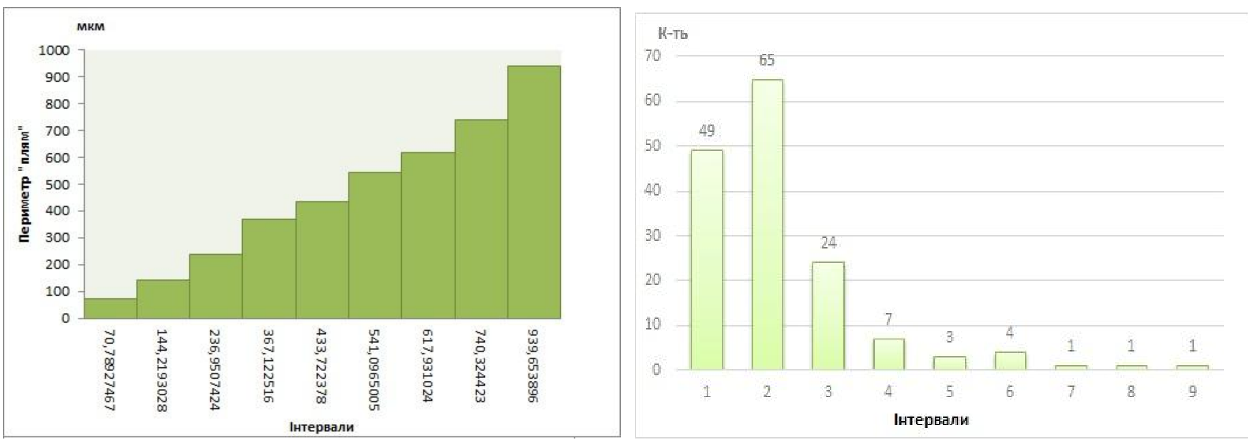
Determinining the optimal bit detail level

Correlation of image resolution	Theoretical	Practical	Correlation theoretical/practical
300 to 600	2	1,9991	0,9996
300 to 900	3	3,0279	1,0093
300 to 1200	4	4,0378	1,0094



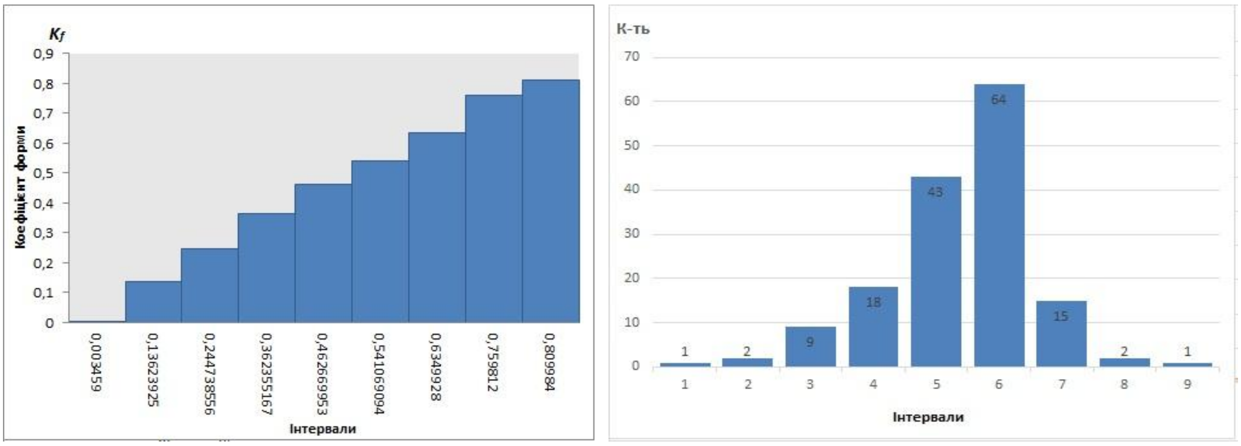
a *b*

Fig. 3. Hystogram of area distribution (a) and their quantitative characteristics (b)



a *b*

Fig. 4. Hystogram of distribution by perimeter (a) and its quantitative characteristics (b)



a *b*

Fig. 5. Hystogram of distribution by form factor (a) and their quantitative characteristics (b)

Using the archive data of observations on the washout, which was conducted at organized hospitals within the Gorohiv district, Polissya branch of the Institute of NSC IGA named after O. N. Sokolovsky, confirmed that most of this territory is negatively affected by erosion processes, in particular, water erosion. Also the preliminary field studies of the planar soil washing [Melnyk V. M., 2012], form a sufficiently complete picture of the geometric changes of the surface to be studied. In our case, the volume of washed soil during cyclic observations was 11.2 t / ha/year (Melnyk V. M., Mendel V. P., 2012) and 12.3 t/ ha /year.

This approach allows us to determine not only agricultural areas exposed to water or wind erosion but, when using cyclic distant observations, to trace the dynamics of changes, which greatly simplifies the search for areas of the most degraded processes. This allowed location of the most problematic places and to coordinate further detailed research.

Accordingly, it has been established that the method of determining the main characteristics of planar objects of erosion-hazardous territories (areas, perimeters, and forms) with the help of modern software is more efficient and no less effective.

Scientific novelty and practical significance

The method of the step-by-step elaboration of binary images for the study of erosion processes based on aerial photography (methods of binarization, segmentation, and mathematical morphology) were used. This approach made it possible to get a clearer picture, and accordingly, more accurate results of morphological and planimetric definitions. This methodology made it possible to obtain quick statistical information on the condition of agricultural lands, and to direct further research on erosion in significant areas of the territory.

The prospect of such studies is to obtain the morphological and planimetric characteristics of the blurred "spots", which depend on the morphometric properties of the relief and type of soil. In turn, the use of combined studies of remote and ground methods, including REM-studies of soil microstructure, will allow analyzing the erosion process in a variety of ways in order to create new predictable mathematical models of water and wind erosion and the introduction of modern anti-erosion measures.

Summary

1. The principle possibility of using a well-known method for the analysis of aerial photography of an erosive-hazardous territory was confirmed in order to plan further erosion studies.

2. The results of the work showed the effectiveness (efficiency and simplicity) of the offered automatic method in the analysis of aerial photography in binary form. The processing time of one image is 11 minutes. The location of the possible output of soil-forming rocks on the surface and, respectively, the approximate area of the territories exposed to water erosion (38.7 % of the total) were determined.

3. Further application of the obtained results of the image processing of remote sensing materials

is planned to be used when creating new forecast mathematical models of water and wind erosion and the introduction of modern anti-erosion measures.

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ЗАСТОСУВАННЯ МЕТОДІВ МАТЕМАТИЧНОЇ МОРФОЛОГІЇ ПІД ЧАС ДОСЛІДЖЕННЯ ЕРОЗІЙНИХ ПРОЦЕСІВ ЗА МАТЕРІАЛАМИ АЕРОФОТОЗЙОМКИ

Мета. Встановлення планового розподілу ерозійних “плям” на сільськогосподарських землях на основі опрацювання бінарних зображень матеріалів аерофотознімання із застосуванням методів морфолого-планіметричного аналізу. **Методика**. Запропонована методика основується на застосуванні нелінійних операторів, які математично описуються теоретико-множинним формалізмом. Математична морфологія використовує два основних морфологічні фільтри, які можна представити як послідовні комбінації двох етапів аналізу зображення на основі використання базових морфологічних операторів: стиснення і розширення. **Результати.** Для отримання максимальних характеристик зображення запропоновано опрацювати в такій послідовності: бінаризація, сегментація та морфолого-планіметричні визначення. Зміст бінаризації полягає у тому, що світлі плями, які показують вихід грунтотвірних порід на поверхню можна відділити за відомим методом проф. В. М. Соколова з послідовним розбиттям пікселів. Такий процес є найвживанішим у цифровій фотограмметрії. Поданий відповідний математичний апарат. Наступним етапом опрацювання бінарного зображення було виділення суміжних границь та ділянок шляхом сегментації методом Лапласа. У такому разі оцінено дві різні контрастності областей А і В. Для встановлення границь їхнього поділу оцінюються знаки другої похідної перепаду контрастності. Запропоновано здійснювати сегментацію згідно з теорією графів. Ілюстрацію такої сегментації представлено графічно. На третьому етапі опрацювання проводяться морфолого-планіметричні визначення на досліджуваному зображені з використанням піксельних масок розміром 2×2. Як результат можна обчислити статистичні розподіли плям на аерофотознімках за площею, периметром та фактором форми. **Наукова новизна**. Запропонована методика поетапного опрацювання аерознімків основується на використанні методу бінаризації та сегментації, які дають змогу отримати чіткіше зображення, а відповідно і точніші результати морфолого-планіметричних визначень. **Практична значущість**. За запропонованим алгоритмом були проаналізовано деякі морфометричні характеристики плям на аерофотознімках: площа, периметр та фактор форми. Приклади застосування, що підтверджують універсальність запропонованого методу під час аналізу зображень у мікрофотограмметрії наведено у роботі [Мельник, 2013].

Ключові слова: аерофотознімки, сегментація, піксельна маска, бінаризація, ерозія, морфологічні фільтри.

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