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# HOMOMORPHIC FILTERING IN DIGITAL MULTICHANNEL IMAGE PROCESSING

**Purpose.** The purpose of this article is to develop a preprocessing method for digital multispectral remote sensing images obtained through optical and infrared means in the electromagnetic spectrum. The method aims to ensure invariance with respect to positional formation conditions that determine spatial and radiometric resolution. By implementing homomorphic filtering in this method, we can significantly increase the informative value of processed imagery.

**Methodology.** The problem solving, including the development of the spatial and radiometric resolution increase ways for multispectral geospatial data are based on the methods of brightness spatial distribution fusion, methods of data dimension reduction, de-correlation techniques and geometric correction of image spatial distributions.

**Findings.** The method of preprocessing digital remote sensing data has been developed, which is a component of the methodology for identifying geometric shapes (GS) of objects in multi-channel aerospace images, allowing for a significant improvement in their recognition efficiency when noise is present.

**Originality.** The method of preprocessing photogrammetric scenes using homomorphic filtering to enhance their informational significance is proposed. The method ensures invariance to positional conditions of fixation, improves the accuracy of further recognition, eliminates the drawbacks of known methods associated with the existence of parametric uncertainty dependence, the features of fixation of species information, low values of information indices of synthesized images, and computational process peculiarities.

**Practical value.** Practical value is consists in improving of identification accuracy of objects GS in digital geospatial data, in significant increasing of raster multispectral images information value and in rising of automated image processing efficiency. The use of the method can greatly enhance the value and usefulness of multispectral photogrammetric images in a wide range of applications, from environmental monitoring to urban planning.

**Keywords:** *object identification, geometric form, digital photogrammetric image, information value, homomorphic filtering*

**Introduction.** At present, information technologies are widely used in digital image processing. Data restoration is a highly researched field where the original image is restored from a noisy image. Correcting and analyzing satellite radar images (SAR) is a complex and pressing task in image processing due to the arbitrary constructive and destructive noise that produces multiplicative noise called speckle noise throughout the imagery [1].

There are numerous despeckling techniques and filters available in both spatial and frequency domains to manage speckled SAR imagery while preserving critical information such as edges, boundaries, and objects. Homomorphic filtering denoising schemes are highly effective and adaptive, whereas non-homomorphic denoising techniques, though also effective, are less commonly used due to their complexity. It has been observed that Bayesian approaches in transform domains show better results than those in spatial domains. However, some non-Bayesian approaches can give comparable results to Bayesian approaches in transform domains. In despeckling based on compressed sensing, it is known that multiple degraded images can be merged to obtain a high-quality image. Therefore, compressed sensing is utilized to obtain multiple SAR images from a single SAR image based on fusion techniques [2].

In [3], an automated processing technology of photogrammetric scenes was proposed. The technology employs an object-based approach to classify, analyze, and identify objects on the Earth's surface by considering their unique properties. A multiscale segmentation method was utilized to obtain objects, while various features such as geometric, spectral, spatial, texture, and statistical features were calculated to identify different types of objects accurately. Based on the calculated features, a decision on the object class is made using a model based on fuzzy inference. The images with poor contrast may lead to the wrong interpretation and classification of the image data including remote sensing applications [4].

The tasks of pattern recognition and image classification are particularly important in the remote sensing area for satellite imagery processing [5, 6]. Currently, there exist numerous satellites capable of producing high-quality images of the Earth's surface. The great amount of acquired data requires methods for their fast processing and extraction of useful information about the objects on the images [3]. Photogrammetric scenes of the fixed object obtained in the different spectral ranges have different spatial, spectral and radiometric differences and, as a result, differ significantly in the spatial distributions of brightness. However, every such image has a separate information significance in terms of presenting the characteristics of the object in its visual form.

In digital image processing, homomorphic filtering is a commonly used method for transforming multiplicative noise into additive noise, making it easier to apply other additive noise restoration models. This method is easy to implement. However, non-homomorphic filtering methods work directly on multiplicative noise, which can be comparatively difficult to handle. Homomorphic filtering is typically used to improve non-homogeneous illumination in images, and it is known to be an adaptive and robust method compared to others. Moreover, efficient linear and non-linear filters, as well as non-Bayesian methods, can be easily incorporated into homomorphic filtering schemes [1].

Therefore, the problem of creating the geometric models of information representations of such images acquires a special meaning. Models are to be invariant with respect to the factors of formation, taking into account their partial certainty [3]. It is important to develop on this basis the methods of the image preprocessing to increase the information value of the processed ones.

**Literature review.** The main aim of image enhancement is to improve the visual quality or appearance of remote sensing imagery. Homomorphic filtering is a frequency-domain technique that aims at a simultaneous increase in contrast and dynamic range compression [7]. It is mainly utilized for non-uniformly illuminated images in medical, sonar photogrammetric scenes, etc. [8] for edge enhancement that makes the image details clear to the observer. In homomorphic filtering, the illumination and reflectance components are processed using a discrete Fourier transform, which improves the algorithm performance to a limited extent [9]. Recently, fractional-order partial differential equations have been explored in imagery enhancement to achieve a balanced improvement between contrast enhancement and dynamic range compression. Fractional-order derivatives are applied to image enhancement to improve edge information, make texture details clearer, and retain homogeneous regions [10, 11]. The article [12] presents homomorphic filtering for image enhancement using fractional calculus. This method nonlinearly enhances the high and mid frequencies while retaining the low frequencies. However, the authors have not explained the selection of the parameters required for homomorphic filter and fractional order.

The homomorphic enhancement method is effective in eliminating the impact of uneven illumination in frequency domain algorithms. This method can compress the dynamic range of the image, expand the gray levels of the target object, and enhance the data details. In the paper [13], a hybrid algorithm is proposed to further improve the image enhancement process. This algorithm employs Gaussian filter processing to enhance the data details in the frequency domain and top-hat/bottom-hat transforms to smooth the image contours in the spatial domain. The article [4] presents an image enhancement method based on fractional-order derivatives and genetic algorithm to boost the homomorphic filtering performance. Homomorphic filtering is used to attenuate the contribution made by the illumination and amplify the reflectance components of an image. This work uses a fractional-order derivative to enhance the mid- and high-frequencies and preserve the low-frequencies. The enhancement of the image depends on the parameters required for the homomorphic filter function and fractional-order value, which are not the same for all types of imagery. In [1] the homomorphic filtering scheme is proposed that uses anisotropic diffusion in db2-type wavelet transform. Linear and non-linear filters are applied to the approximate part of the image to eliminate blurring, and method noise thresholding is utilized to restore the unfiltered part of the despeckled image. The proposed method is tested on real datasets of SAR data with correlated and uncorrelated speckle noise.

The automated classification of urban land cover is a well-known problem in remote sensing. Multispectral aerial images are increasingly used for regular maps of cities. EOS Data Analytics has developed a web-service that employs remote sensing images of high spatial resolution for automated recognition of buildings, vegetation, water bodies, etc. in cities to increase the efficiency of updating maps of cities [14]. With the advent of high-resolution remote sensing imagery, the requirements for classification are increasing. Classification of aerial scenes has led to several studies on deep learning in the field of remote sensing. A methodology for evaluating the accuracy of object recognition using high spatial resolution remote sensing images and neural networks is proposed in [15]. The classical methods of image classification relate to data clustering algorithms. These methods are inferior in accuracy to modern methods of image classification [16]. Nowadays they are used in combination with different image processing techniques. The convolutional neural networks architectures for per pixel image categorization have been developed too. They allow one to perform the segmentation and thematic classification of photogrammetric scenes [17]. The authors of [18] proposed an improved FCN (Fully Convolutional Network) model for accurate classification of high-resolution remote sensing imagery. In [19], an end-to-end framework for the dense, pixel-wise classification of satellite imagery with convolutional neural networks was proposed. The classification of satellite imagery using neural networks is not always convenient due to lack of training data. In [20], an object-based approach for road extraction from images was proposed. That approach incorporates various objects descriptors, the capabilities of the fuzzy logic system and the ant colony algorithm for optimization of the road network. In [21], an inclusive semiautomatic method for image classification was proposed. The classification presents the configuration of the fuzzy functions and fuzzy rules.

A number of studies on the preprocessing of multi-tone raster images focus on improving their visual quality without taking into account the physical mechanisms of the imagery information fixation, including inter-channel correlation, which makes it impossible to determine the information value of the photogrammetric scenes from the standpoint of analysis and interpretation (Brovey color normalization method). Other studies are devoted to solving this problem based on the calculation of the statistical parameters of digital images (principal component analysis method), the determination of which is difficult on large dimensions of primary data. The issue of the decorrelation of primary imagery data is addressed in a number of studies. They are based on the transition to color-difference metrics (color-metric processing methods). But such methods take into account only the contribution of spectral information contained in the primary multi-tone images. Homomorphic filtering is used to remove multiplicative noise in the image.

The essence of the homomorphic image processing is to normalize the brightness levels, namely narrowing their dynamic range, and simultaneously increase its contrast, which should significantly increase the information value of the processed image.

**The purpose** of the paper is to develop the preprocessing method of digital multispectral remote sensing images obtained by iconic means in optical and infrared ranges of the electromagnetic spectrum, ensuring invariance according to positional formation conditions which determine spatial and radiometric resolution. The condition that the method must meet is the preservation of linearity between the formed and primary data, which is due to the problems of the subject area.

**Methods.** Brightness can be considered a low-frequency component, because the light changes in space rather slowly, and the photogrammetric scene (component of reflectivity) can be considered a high-frequency signal, because the image may contain small details, which leads to rapid changes in its texture and configuration. The product of these components is the resulting signal in the primary image

$$f(x, y) = f_i(x, y) \cdot f_r(x, y),$$

where $f(x, y)$ is image intensity; $f_i(x, y)$ – illumination function; $f_r(x, y)$ – reflectivity function; $x, y$ – discrete spatial variables.

In order to narrow the dynamic range, the component of illumination is to be processed, and in order to increase the contrast, the component of reflectivity is to be processed. To do this, by homomorphic processing, the problem is reduced to the linear one

$$f^*(x,y) = \ln\left[f(x,y)\right] = \ln\left[f_i(x,y) \cdot f_r(x,y)\right] = \\ = \ln f_i(x,y) + \ln f_r(x,y) = f_i^*(x,y) + f_r^*(x,y),$$

where $f^*(x, y)$ is image density; $f_i^*(x,y)$ and $f_r^*(x,y)$ are illumination density and reflectivity density respectively.

The multiplicative components of the remote sensing imagery are separated and can be further processed independently of each other. To the received signal $f^*(x, y)$ the linear filter of high frequencies is used. Then, according to properties of linear systems, we receive the expression

$$g^*(x,y) = g_i^*(x,y) + g_r^*(x,y),$$

where $g^*(x, y)$ is the image density processed; $g_i^*(x,y)$ and $g_r^*(x,y)$ are illumination density processed and reflectivity density processed respectively.

It should be noted that the linear processing was performed by using the high-speed convolution methods performed in two measurements.

In order to return to the original space, we use potentiation

$$g(x,y) = \exp[g_i^*(x,y) + g_r^*(x,y)] = \\ = \exp[g_i^*(x,y)] \cdot \exp[g_r^*(x,y)] = g_i(x,y) \cdot g_r(x,y),$$

where $g(x, y)$ is image intensity processed.

The standard characteristics of the information value of the digital photogrammetric image recorded by the iconic means of remote sensing in a number of spectral ranges are information entropy and signal entropy. Information entropy is one of the main characteristics of the information value of a multispectral raster image and is calculated by the expression

$$E(x) = -\sum_{(k=0)}^{(N-1)} p_k \cdot \log_2 p_k, \quad (1)$$

where $N$ is the number of brightness levels; $p_k$ – the frequency of the brightness $k^{th}$ level of the $x$ sample; $k$ – an integer brightness level that belongs to the interval [0, 255].

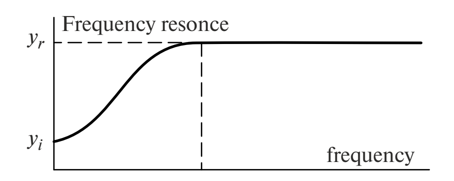


*Fig. 1. The frequency response of the linear filter of homomorphic image processing to narrow the dynamic range and to increase the contrast (when selecting the indicators of degree: $y_i < 1$ to modify the illumination function; $y_r > 1$ to modify the reflectivity function*

Signal entropy is a measure of the multispectral image information value

$$E_{sign}(x) = -\sum_{(i=0)}^{(N-1)} p_i \cdot \log_2 p_i, \quad (2)$$

where $p_i = \dfrac{i \cdot x_i}{\sum_{j=0}^{255} j \cdot x_j}$ is an analogous to the frequency of the brightness $i^{th}$ level of the $x$ sample; $i$ – an integer brightness level that belongs to the interval [0, 255].

In the paper, these information characteristics are used to assess the effectiveness of the developed algorithm and the resulting images. The criterion of the maximum of the given information characteristics is accepted. The images obtained after the processing are compared with primary pictures/snapshots according to this criterion.

The homomorphic processing of the imagery data is aimed at removing (filtering) from the primary photogrammetric scenes the part of the excess (imported) information introduced by the influence of the imaging equipment of the optical complex to the image of the fixed earth area during the survey.

The proposed homomorphic processing algorithm consists of the stages:

1) calculation of the two-dimensional fast Fourier transform of the two-dimensional discrete signal that supplies the original image;

2) calculation of the inverse two-dimensional fast Fourier transform from the natural logarithm of the signal power spectrum that supplies the processed image;

3) determining of the optical transfer function of the shooting equipment (Fig. 2);

4) calculation of the inverse two-dimensional fast Fourier transform from the natural logarithm of the two-dimensional fast Fourier transform of the optical transfer function;

5) removal of information regarding the hardware influence, the carrier of which is the calculated optical transfer function, on the characteristics of the processed image;

6) reverse transformations and restoration of the synthesized image.

**Results.** It should be noted that the spectrum calculation was performed using a two-dimensional Fast Fourier transform.

As initial data for research of the developed digital image homomorphic processing algorithm, the primary imagery data received from an optical complex of the Ukrainian spacecraft Sich-2 are used. The images in its four spectral intervals of optical range are given in Fig. 3. The fragments of images of the corresponding channels obtained as a result of the investigated method of homomorphic filtering are shown in Fig. 4.

The image fragments (Fig. 4) were assessed by the values of information entropy and signal entropy, calculated by the corresponding expressions (1, 2). The obtained data are given in Table 1.

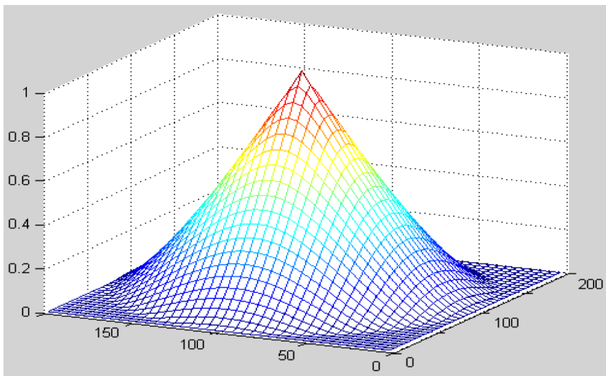


*Fig. 2. An example of a normalized two-dimensional optical transfer function of the image*

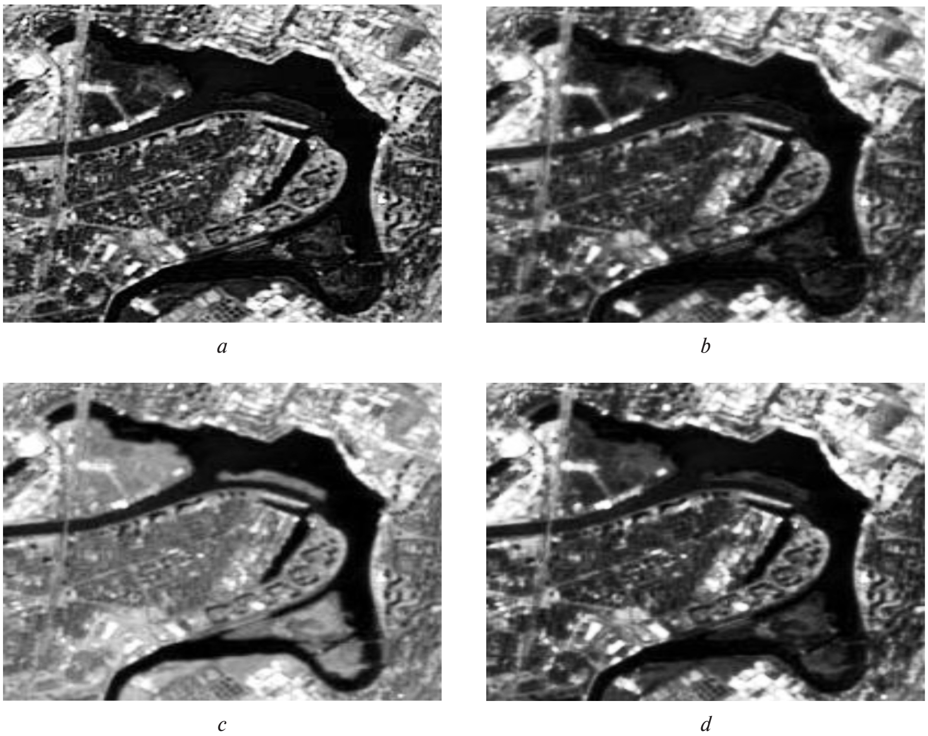


*Fig. 3. The primary imagery data:*
*a – panchromatic; b – infrared; c – red; d – green*

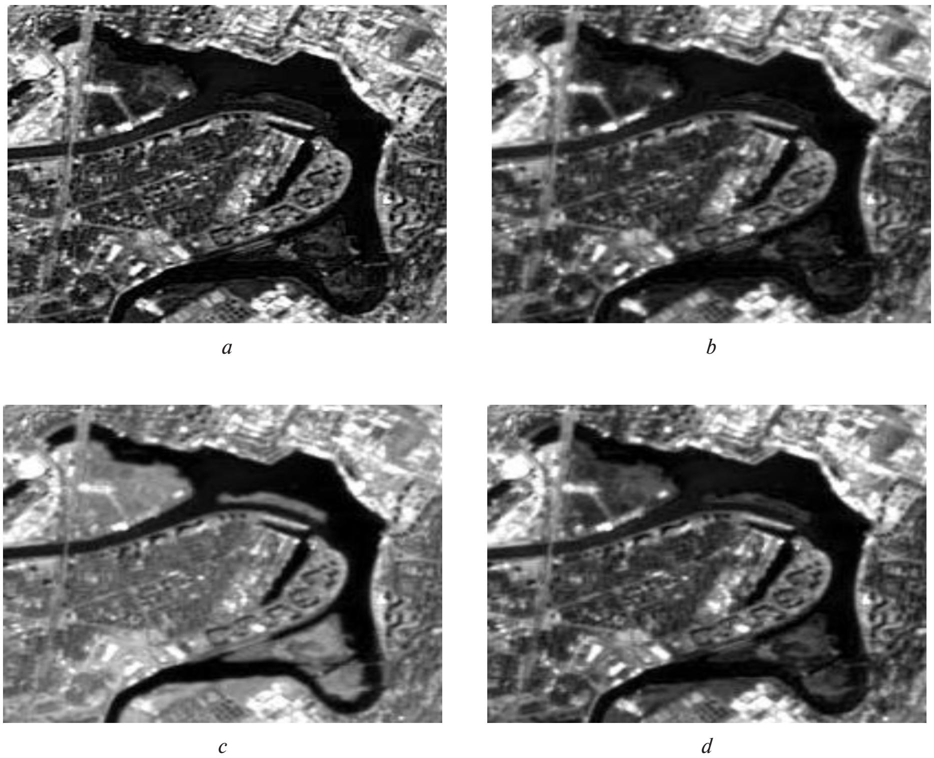


*Fig. 4. The results of the homomorphic processing:*
*a – panchromatic; b – infrared; c – red; d – green*

According to Table 1, the values of information and signal entropy for the original photogrammetric scenes fixed by the optical system scanner of the Ukrainian spacecraft Sich-2, and the corresponding processed images are increasing, and therefore the information value of these images increases due to the application of homomorphic filtering and cleaning of the image from noise introduced by the camera.

The studied method was also applied to the original data recorded in nine spectral bands of electromagnetic radiation by the Aster scanner (Terra spacecraft). For the original and images obtained as a result of the homomorphic filtering method, the corresponding characteristics of informational significance were calculated and summarized in Table 2.

*Table 1*

Information entropy and Signal entropy (Sich-2)

| Processing Channel | Information entropy | | Signal entropy | |
|---|---|---|---|---|
| | Initial | Processed | Initial | Processed |
| Panchromatic | 7.2322 | 7.3386 | 7.2733 | 7.4386 |
| Infra-red | 6.9568 | 7.1269 | 7.0296 | 7.2923 |
| Red | 6.8357 | 7.0135 | 6.8666 | 7.1035 |
| Green | 6.8247 | 7.0093 | 6.8983 | 7.1609 |

*Table 2*

Information entropy and Signal entropy (Aster scanner of Terra spacecraft)

| Processing Channel | Information entropy | | Signal entropy | |
|---|---|---|---|---|
| | Initial | Processed | Initial | Processed |
| 1 | 4.4391 | 5.1265 | 4.6871 | 5.3012 |
| 2 | 4.4538 | 5.0275 | 4.7023 | 5.3642 |
| 3 | 4.8832 | 5.3846 | 4.6908 | 5.6993 |
| 4 | 4.7862 | 5.4582 | 4.4723 | 5.4018 |
| 5 | 4.5897 | 5.2612 | 4.5011 | 5.2771 |
| 6 | 4.7898 | 5.2556 | 4.5103 | 5.1133 |
| 7 | 4.6579 | 5.1349 | 4.6707 | 5.8206 |
| 8 | 4.8237 | 5.3015 | 4.7012 | 5.2071 |
| 9 | 4.5287 | 5.1054 | 4.5166 | 5.2323 |

The results obtained for the Aster scanner confirm the conclusions made above when performing homomorphic processing according to the proposed algorithm of the primary species data obtained from the optical complex of the Sich-2 spacecraft in four spectral intervals of the optical range.

According to Table 2, we also observe the expected increase in the values of the information characteristics of the processed images. Thus, the work shows a significant increase in the informational significance of raster multispectral images and an increased efficiency of automated image processing obtained from sensors with different characteristics of capturing spectral data, namely from the imaging equipment of the Terra and Sich-2 spacecraft, which confirms a certain degree of universality of the proposed method.

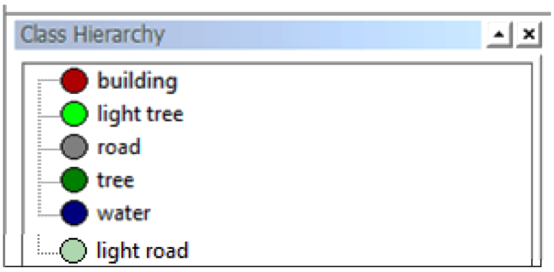


*Fig. 5. Hierarchy of classes for classification*

**Implementation of classification based on homomorphic processing.** Modern software environments for the identification of objects' geometric shapes (GS_ (Definiens Developer, the corresponding toolbar of the ENVI environment) perform image analysis based on the rules of fuzzy logic. This approach consists in deciding whether an object belongs to a certain class or to some of the existing classes to a certain degree – the degree of belonging depends on the degree of satisfaction of the description of a certain class, which ensures a more flexible classification of objects.

In this work, the Standard Nearest Neighbor classification of geometric shape objects of the Definiens Developer software product was used, which was implemented in compliance with the rules of fuzzy logic according to the "nearest neighbor" principle. The degree of belonging to a certain property of the object is determined by the function of belonging to the class. Fuzzy logic supports combinations of different types of object properties (geographic, texture data, hierarchical relationships) within the definition of one class due to the use of various logical operations ("AND", "OR", "NOT", etc.).

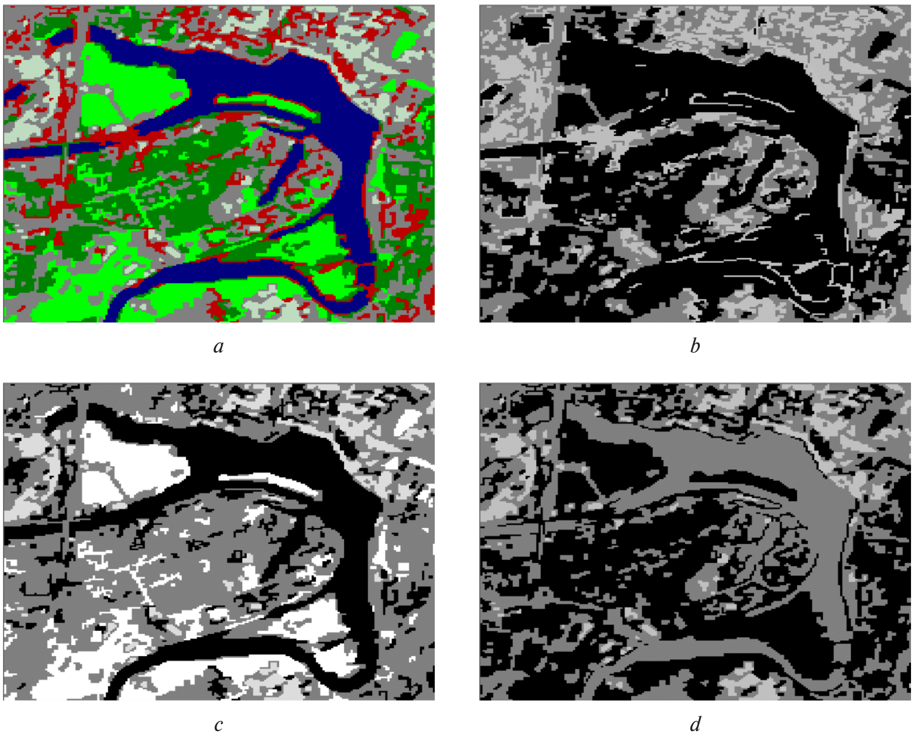

*Fig. 6. Classification results for the primary image:*
*a – RGB image; b – the first channel; c – the second channel; d – the third channel*

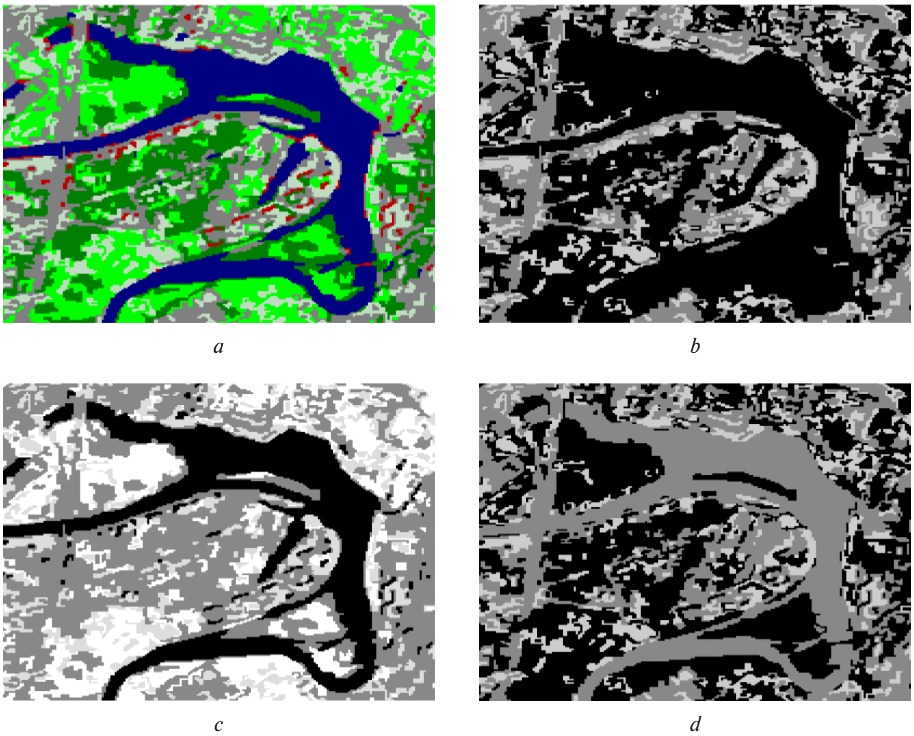

*Fig. 7. Classification result for an image with prior homomorphic filtering:*
*a – RGB image; b – the first channel; c – the second channel; d – the third channel*

Data analysis and classification of image objects GS in the Definiens Developer environment is performed on the basis of the so-called class hierarchy, which includes all classes of the classification scheme.

For the image classification, the following object classes were created and used: road ("road", "light road"), buildings ("building"), vegetation ("tree", "light tree"), water surface ("water"). The window with the corresponding hierarchy is shown in Fig. 5.

The results of object GS classification based on fuzzy logic rules for raw images without processing are shown in Fig. 6, and the corresponding classification results for the image with prior homomorphic filtering are presented in Fig. 7 in the form of RGB images and by channels.

Visual analysis of Figs. 6, 7 reveals a high level of detail of the image objects GS of individual channels as a result of the classification of the image itself after performing homomorphic processing, which indicates the significant efficiency of image processing based on filtering and the excellent quality of the performed geometric shape identification.

Thus, the use of the developed method makes it possible to increase the efficiency of identification of objects GS visualized on images obtained as a result of homomorphic processing, in comparison with visual data obtained directly from sensors.

Significantly qualitative results of identification of objects GS based on the rules of fuzzy logic were obtained when using pre-processing of images based on the homomorphic filtering algorithm, provided that the linearity between the generated and primary data is preserved. The method is invariant with respect to formation factors, taking into account their partial certainty.

**Conclusions.** The method for preprocessing digital images based on their homomorphic filtering has been developed. It allows increasing the information value of primary data by the criterion of maximizing the standard information characteristics of digital images: information entropy and signal entropy. It is proposed to use the method of high-speed convolution performed in both image measurements during linear processing. This allows processing the image of the current multispectral image channel as a two-dimensional discrete signal without requiring additional transformations of the corresponding spatial brightness distributions, which provide a specific image. This way of image processing simplifies program code and saves computing resources.

The algorithm gives qualitative results in terms of spatial and radiometric resolution, integral characteristics of the geometric form, other characteristics of information value. Homomorphic processing allows one to normalize the brightness levels of the photogrammetric image and at the same time increase its contrast. This also additionally removes multiplicative noise from the processed image, which is due to the peculiarities of the method and the use of specific intermediate structural elements in its composition. These areas are of scientific interest for further research.

**Further development** of the proposed research can be carried out in the direction of new ways of transforming the spatial distributions of brightness during pre-processing through the use of other approaches of homomorphic filtering in order to increase the efficiency of the proposed algorithm. The use of the obtained results in scientific research is expedient in the development of new methods of geometric modeling of the processes of formation and pre-processing of digital multispectral images.

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## Гомоморфна фільтрація в обробці багатоканальних цифрових зображень

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**Мета.** Розробка методу попередньої обробки цифрових багатоспектральних зображень, отриманих за допомогою оптичних та інфрачервоних засобів дистанційного зондування Землі. Цей метод забезпечує інваріантність щодо геометричних і радіометричних умов фіксації геопросторових даних.

**Методика.** Під час вирішення задачі, пов'язаної з розробкою методу попередньої обробки цифрових багатоспектральних даних дистанційного зондування Землі, були використані методи злиття, зменшення розмірності даних, декореляції, радіометричної й геометричної корекції фотограмметричних сцен. Завдяки застосуванню гомоморфної фільтрації, було досягнуто значне збільшення інформативної значущості цих зображень за наявності шумової складової.

**Результати.** Розроблено метод попередньої обробки цифрових фотограмметричних даних, який є складовою методології ідентифікації геометричних форм об'єктів на багатоканальних аерокосмічних зображеннях, що дозволяє суттєво підвищити ефективність їх розпізнавання.

**Наукова новизна.** Запропоновано метод попередньої обробки багатоканальних аерокосмічних зображень, що використовує гомоморфну фільтрацію з метою підвищення їх інформативності. Цей метод дозволяє підвищити точність подальшого розпізнавання геопросторових даних. Метод також позбавлений недоліків відомих методів, що пов'язані з параметричною невизначеністю, низькими показниками радіометричної розрізненості синтезованих зображень та обчислювальними складнощами.

**Практична значимість.** Полягає в підвищенні точності розпізнавання аерокосмічних зображень, у суттєвому збільшенні інформативності багатоканальних цифрових геопросторових даних і підвищенні ефективності їх автоматизованої обробки. Використання методу може значно підвищити цінність і корисність мультиспектральних фотограмметричних зображень у широкому діапазоні застосувань, від екологічного моніторингу до міського планування.

**Ключові слова:** *ідентифікація об'єктів, геометрична форма, цифрове фотограмметричне зображення, інформативність, гомоморфна фільтрація*

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