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USE OF ARTIFICIAL INTELLIGENCE IN PHOTOGRAMMETRIC PROCESSING OF DIGITAL DATA

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Abstract. *The article considers the impact of artificial intelligence neural network algorithms on the process of photogrammetric processing of digital images and the formation of dense point clouds.*

It is noted that the integration of machine learning algorithms, in particular deep learning, allows you to automate key processing stages, increase the accuracy of object classification, optimize geometric correction of images and improve the quality of final geospatial products in the form of an orthophotomap of the terrain.

The main stages of the photogrammetric process are described: from collecting primary data to forming orthophotomaps and three-dimensional terrain models. Particular attention is paid to the role of the neural network in improving the density of the point cloud due to the correct interpretation of points on digital images, object classification and reducing the influence of the human factor.

The challenges associated with the need for large volumes of high-quality training data are identified. The prospects for the application of artificial intelligence neural networks in photogrammetry and the need for further research in this direction are substantiated.

Keywords: *neural network, artificial intelligence, photogrammetry, machine learning, point cloud, orthophotomap, 3D model, digital image.*

Problem statement

In the modern digital environment, artificial intelligence plays a key role in transforming many areas of human activity.

One of the current problems is to increase the efficiency of photogrammetric processing of digital images and 3D scanning data of the territory. Traditional algorithms have limitations in terms of productivity, accuracy, speed and automation of processes. At the same time, the integration of artificial intelligence elements, such as neural networks and deep machine learning methods, allows to significantly improve the classification, interpretation, determination of shapes, sizes and spatial position of terrain objects [10].

This opens up new opportunities for creating high-precision orthophoto maps of the terrain and 3D models, reducing errors and optimizing the processing of large volumes of remote sensing data [7,9].

Analysis of recent research and publications

Modern scientific research demonstrates the active use of unmanned aerial vehicles in photogrammetric work in the process of obtaining digital images and their further processing.

Domestic authors, in particular Butenko E.V. and Krasnosilska A.A. [12] , focus on the integration of neural networks for automating the classification and interpretation of terrain objects. The works of Shevchenko A.I. [13] and Guralyuk A. [14] consider the role of artificial intelligence in the digital transformation of geoinformation technologies.

The team of authors Butenko and Kulakovskyi devoted their research to studying the issue of the effectiveness of using unmanned aerial vehicles to solve various problems of geodesy and land management [1].

Analysis of scientific works of foreign scientists demonstrates active introduction of artificial intelligence in photogrammetric processes of digital data processing, in particular in automated 3D modeling, object classification and processing of point clouds.

The work of Rongjun Qin and Armin Gruend considers the application of machine learning for semantic interpretation of spatial data, which allows to increase the accuracy of digital terrain models, namely the application of machine learning at different stages of the photogrammetric process: from data collection and camera calibration to the generation of digital surface models and semantic interpretation. The authors analyze how artificial intelligence can automate traditionally manual processes, increasing the accuracy and efficiency of 3D modeling [16].

Shahad Abbood [15] and colleagues analyze deep learning algorithms that optimize image reconstruction and calibration processes in the process of digital sensor calibration. Their research opens up new opportunities for multisensor integration and intelligent image analysis.

The article by Mi Wang [18] substantiates the theoretical basis for the transition to intelligent geographic information systems, where large models play a key role in 3D reconstruction, semantic analysis and automation of photogrammetric processes.

The article by Fabio Remondino [17] confirms that artificial intelligence is able to automate complex photogrammetric tasks, reducing the need for manual intervention. Overall, these studies indicate the transformation of photogrammetry towards intelligent geographic information systems.

Hlotov and Hunina analyze the possibilities of using unmanned aerial vehicles in various types of aerial survey work and their effectiveness [2].

The works of Irschara et al. [3], Remondino et al. [5] and Sauerbier et al. [6] justify the need for full automation of photogrammetric processing of digital images obtained from unmanned aerial vehicles.

Particular attention should be paid to the studies of the authors Butenko and Poshtar [7] and Pokatayev [9], who investigate the integration of neural networks into photogrammetric software algorithms and focus on the role of artificial intelligence in the management of territorial complexes in Ukraine, especially emphasizing their potential for the digital transformation of urban infrastructure.

Practical aspects of the use of artificial intelligence in the process of analyzing digital data are given in the publications Probesto [10] and Gigacloud [11], which describe the principles of machine learning and its application in geographic information systems.

Thus, a review of scientific sources confirms the relevance of the chosen direction of scientific research on the use of artificial intelligence for automation, increasing the accuracy and efficiency of photogrammetric processing of digital data.

Research objective. The purpose of the article is to study the prospects for using artificial intelligence to automate, increase the accuracy, and optimize the processes of photogrammetric processing of digital images.

Materials and methods of scientific research

In the course of scientific research on the application of artificial intelligence in photogrammetric processing of digital data, the following methods of scientific research were used: analytical, abstract-logical, structural-functional and comparative.

The analytical method investigated modern technologies for photogrammetric processing of digital images used to create orthophotomaps, digital terrain models and three-dimensional terrain models.

The abstract-logical method allowed us to assess the prospects for integrating artificial intelligence into photogrammetric software, in particular deep learning algorithms that help automate the processes of classification, geometric correction and interpretation of objects.

The structural-functional method analyzed the stages of photogrammetric processing: image improvement, point cloud formation and classification, and creation of the final product in the form of an orthophotomap of the terrain.

The comparative method was used to assess the effectiveness of using artificial intelligence in photogrammetry compared to traditional approaches, taking into account accuracy, processing speed, and quality of the final data.

Research results and their discussion

In information technology, artificial intelligence is a neural network of hardware or software systems, built on the principle of neurons in the human brain. In fact, it is a computational system of gradual actions, based on a set of connected nodes that are interconnected.

In turn, modern technology of photogrammetric processing of digital images, the formation of dense point clouds is a key stage for creating high-precision geospatial and cartographic products, such as orthophotomaps, digital terrain models and three-dimensional terrain models, which are widely used in various industries, including cartography, land management, environmental monitoring, agriculture and urban planning [2,3].

The essence of photogrammetric processing is the use of digital images to create planning and cartographic materials. Its main stages are: image collection and enhancement, dense point cloud formation, its classification, creation of orthophotomap and digital models.

One of the most promising areas in this context is the integration of artificial intelligence technologies into software for photogrammetric data processing. Rapid progress in the field of machine learning, in particular deep learning methods, opens up fundamentally new opportunities for automating complex processes, increasing the accuracy of object recognition and classification, optimizing geometric correction of images and generally increasing the efficiency of photogrammetric production [1,10].

The main stages of integrating artificial intelligence into photogrammetric data processing programs include: improving the original digital images; forming a point cloud and its improvement; classifying a dense point cloud; forming the final processing product, an orthophotomap [6,7].

Photocorrection of digital images is an important stage in the process of processing visual materials, aimed at improving their quality and eliminating various defects. This process consists of several sequential steps, each of which plays a role in achieving the desired result.

1. Image analysis: At the initial stage, it is necessary to carefully examine the image to identify existing shortcomings. These may include:

2. Exposure errors: insufficient or excessive illumination of the image.

3. White balance errors: incorrect display of colors, which leads to their unnaturalness.

4. Low contrast: insufficient difference between light and dark areas, which makes the image dull.

5. Digital noise: the presence of grain or other artifacts.

6. Geometric distortions: distortion of the image caused by the peculiarities of the optics or the shooting angle.

7. Exposure correction: In case of insufficient illumination of the image, its brightness should be increased. If the image is too bright, this indicator should be reduced [19].

One example of the application of artificial intelligence in the field of photogrammetry is the Luminar Neo software from Skylum. This program uses the capabilities of artificial intelligence to improve the quality of images and edit photos [12]. At the initial stage, the necessary raw data is collected, such as digital images obtained from unmanned aerial vehicles. The key requirements for the images are their high quality, the absence of smears, shadows and the presence of sufficient mutual overlap to ensure the possibility of further processing (Fig. 1).

The next stage is to search for corresponding points in the images based on the identification of common characteristic points that are displayed on differ-

Fig. 1. Fragment of a non-uniform digital image that requires correction

ent images, to establish mutual relationships between them, to perform a set of geometric calculations to determine the three-dimensional coordinates of each point based on its projections on different images, which can be improved by an artificial intelligence algorithm [7,11].

At this stage, the spatial orientation of the images relative to each other and their binding to a defined coordinate system is performed. Parameters characterizing the position and angle of inclination of each image in three-dimensional space are determined. To perform this task, reference points whose coordinates are known with high accuracy can be used.

Formation of a dense point cloud, based on previously oriented images, occurs through pixel analysis of digital images. The number of points in the cloud determines the level of detail (cloud density) and the accuracy of the 3D terrain model created from it [2,7].

The resulting dense cloud of three-dimensional points is subject to further analysis and processing. At this stage, procedures for removing unwanted noise (Fig. 2.), refining the spatial coordinates of points, as well as other operations aimed at improving the quality of the final model can be performed [1,4,9].

Based on the processed dense point cloud, a three-dimensional model of the studied area is created. This model can be used for a wide range of tasks, including visualization, conducting various simulations of geodetic and land management works [1,4].

The use of machine learning also contributes to the creation of more detailed and informative orthophotomaps. The ability of artificial intelligence algorithms to analyze complex spectral characteristics of objects and take into account contextual information allows you to identify patterns and dependencies that may not be noticeable with traditional processing methods. This opens up opportunities for obtaining not only geometrically accurate, but also seman-

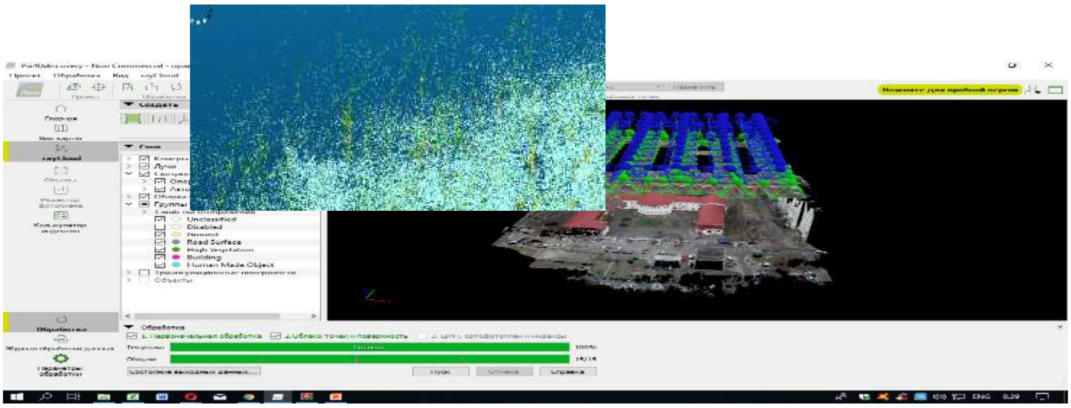

Fig. 2. Formation of a dense point cloud and its improvement by noise removal

Fig. 3. "Breaks" of the orthophotomap image when using different algorithms for its construction

tically enriched orthophotomaps, which can contain additional information about the properties and characteristics of objects in the area.

Despite significant advantages, the use of machine learning in the creation of orthophotomaps is also associated with certain challenges. For effective training of algorithms, large volumes of high-quality spatial data are required, as well as high-quality cloud classification with detailed division of the cloud into different classes of objects (Fig. 3).

The quality of the obtained results directly depends on the quality and representativeness of the data, as well as on the correctness of the choice and configuration of the machine learning model architecture [11].

It is also worth noting that the automation of a significant part of the process of creating orthophotomaps using machine learning leads to a significant reduction in data processing time and a reduction in the need for manual labor. This is especially important when working with large areas or when it is necessary to promptly update cartographic information.

Analyzing the advantages of using artificial intelligence in photogrammetric data processing programs, it is advisable to highlight the following: detection of specific objects in images, which can be useful for identifying specific landscape features or structures in digital images; improving image quality by removing noise, improving contrast, or restoring lost details; rapid creation of orthophotomaps and 3D models based on point clouds; classification of images based on their content for automatic determination of the type of terrain or identification of specific objects; semantic segmentation of images, which allows you to determine which type each pixel of the image belongs to.

Conclusions

The integration of artificial intelligence into photogrammetric technologies opens up new opportunities for increasing the efficiency and accuracy of digital data processing. The use of neural networks allows you to automate key stages of the process that previously required significant human resources, and also significantly improves the accuracy of object detection in images. This has a positive effect on the quality of final geospatial products, such as orthophotomaps and 3D models. Artificial intelligence provides the ability to analyze large volumes of data, classify objects and correct geometric distortions, which increases the overall efficiency of photogrammetric production. At the same time, to achieve high results, it is necessary to ensure sufficient volumes of high-quality data and the correct architecture of machine learning models.

Despite significant achievements, it should be noted that the integration of artificial intelligence into photogrammetric data processing is still at the stage of active development and requires improvement.

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ВИКОРИСТАННЯ ШТУЧНОГО ІНТЕЛЕКТУ ПРИ ФОТОГРАММЕТРИЧНОМУ ОПРАЦЮВАННІ ЦИФРОВИХ ДАНИХ
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Анотація. *У статті розглядається вплив алгоритмів нейромереж штучного інтелекту на процес фотограмметричного опрацювання цифрових знімків та формування щільних хмар точок.*

Зазначено, що інтеграція алгоритмів машинного навчання, зокрема глибокого навчання, дозволяє автоматизувати ключові етапи опрацювання, підвищити точність класифікації об'єктів, оптимізувати геометричну корекцію зображень та покращити якість кінцевих геопросторових продуктів у вигляді ортофотоплана місцевості.

Описано основні етапи фотограмметричного процесу: від збору первинних даних до формування ортофотопланів та тривимірних моделей місцевості. Особлива увага приділяється ролі нейромережі у покращенні щільності хмари точок за рахунок правильної інтерпретації точок на цифрових знімках, класифікації об'єктів та зменшенні впливу людського фактора.

Визначено виклики, пов'язані з потребою у великих обсягах якісних навчальних даних. Обґрунтовано перспективність застосування нейромереж штучного інтелекту у фотограмметрії та необхідність подальших досліджень у цьому напрямку.

Ключові слова: *нейромережа, штучний інтелект, фотограмметрія, машинне навчання, хмара точок, ортофотоплан, 3D-модель, цифровий знімок.*