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INTEGRATION OF ARTIFICIAL INTELLIGENCE AND GIS TECHNOLOGIES IN GEODESY

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Annotation. *The integration of artificial intelligence technologies and geoinformation systems (GIS) is one of the key areas of development of modern geodetic science and practice. The combination of spatial analysis tools with intelligent algorithms creates new opportunities for automating the collection, processing, analysis and presentation of geospatial information. This ensures an increase in the accuracy of geodetic measurements, acceleration of work and improvement of the quality of management decisions.*

Current geodetic research is based on the use of significant spatial data arrays coming from global navigation satellite systems, unmanned aerial vehicles, laser

scanning and remote sensing of the Earth. The processing of such information by traditional methods requires considerable time and human resources. The use of artificial intelligence technologies allows you to automate the search for regularities, the classification of objects and the performance of complex data analysis with a high level of accuracy and speed.

A special role in the development of modern geodesy is played by machine learning methods and neural networks that provide automatic recognition of objects on satellite and aerial photographs. Their use significantly simplifies the process of creating digital maps, updating geospatial databases and observing changes in the earth's surface. This makes it possible to quickly obtain reliable information about the development of territories, the state of land resources and the course of natural processes.

Geoinformation systems provide accumulation, storage, processing and visualization of spatial information, and the use of artificial intelligence significantly expands the possibilities of its analysis and forecasting. The combination of these technologies contributes to the creation of intelligent geoinformation systems capable of automatically detecting trends in the development of territories, assessing potential risks and predicting changes in the natural environment.

One of the promising areas of use of artificial intelligence in geodesy is the automation of processing the results of geodetic measurements, analysis of geospatial information, construction of digital terrain models and updating of cadastral data. Machine learning algorithms provide more accurate determination of coordinates, automatic recognition of spatial objects and timely detection of changes in geodetic materials. A separate direction is land monitoring, within which artificial intelligence technologies are used to assess land use changes, control the state of land resources, and informational support for the territory management process.

The use of intelligent algorithms during the monitoring of engineering structures, transport networks and natural complexes opens up significant opportunities. By analyzing geodetic observations in real time, such systems can predict deformation processes, detect potentially dangerous areas in a timely

manner, and warn of possible emergency situations, which is essential to ensure the safe operation of critical infrastructure.

The integration of artificial intelligence and GIS technologies is also widely used in the field of urban planning and implementation of «smart city» concepts. Geospatial analysis makes it possible to optimize transport infrastructure, plan the development of engineering communications, as well as assess the environmental consequences of urbanization processes. This provides state administration and local self-government bodies with modern tools for sound territorial development planning.

Together with the numerous advantages of introducing artificial intelligence technologies into geodetic activity, it is accompanied by the need to solve the issues of ensuring the quality of raw data, information security and improving analysis algorithms. Further scientific research focuses on increasing the accuracy of machine learning models, developing automated geospatial information processing technologies, and creating new intelligent services for the geodetic industry.

Therefore, the integration of artificial intelligence technologies and geoinformation systems is an important component of the digital transformation of modern geodesy. Their complex use ensures an increase in the efficiency of geodetic works, an improvement in the quality of spatial data analysis, an expansion of territorial monitoring capabilities, and contributes to the development of modern approaches to the management of land resources and infrastructure facilities.

Keywords: *integration, artificial intelligence, GIS technologies, geodesy, geospatial data, machine learning, neural networks, digital maps, monitoring of territories.*

Problem Statement. The modern development of geodesy is characterized by a rapid increase in the volume of spatial data coming from satellite positioning systems, unmanned aerial vehicles, laser scanning and other sources of geospatial information. Traditional methods of processing, analyzing and interpreting such data often require

significant time and labor resources, which complicates operational decision-making and reduces the efficiency of geodetic work [1].

At the same time, geographic information systems (GIS) provide effective storage, visualization and analysis of spatial data, but their capabilities for automatic pattern detection, forecasting and processing of large arrays of information remain limited without the use of intelligent algorithms. In this context, the use of artificial intelligence technologies, in particular machine and deep learning methods, which are able to automate geodetic data processing processes, increase the accuracy of results and reduce work execution time, is of particular relevance.

Despite the significant potential of integrating artificial intelligence and GIS technologies, the issues of developing effective approaches to their complex application in geodesy remain insufficiently researched. There is a need to improve methods of spatial data analysis, automation of geodetic processes and creation of intelligent decision support systems. Therefore, the study of the possibilities of integrating artificial intelligence and GIS technologies in geodesy is an urgent scientific and practical task [2].

Analysis of recent research and publications. The issue of integration of artificial intelligence (AI) and geoinformation systems (GIS) in geodesy is one of the most promising directions for the development of modern geospatial science. In recent years, researchers have been actively exploring the possibilities of applying machine learning, deep learning, and geospatial artificial intelligence (GeoAI) techniques to automate spatial data collection, processing, and analysis. Research shows that the use of AI significantly increases the efficiency of dealing with large amounts of geodata obtained from satellite systems, unmanned aerial vehicles, laser scanning and remote sensing of the Earth [5].

A significant contribution to the development of the GeoAI concept has been made by researchers who consider the integration of geographic sciences, GIS technologies and artificial intelligence algorithms as a new approach to solving complex spatial problems. The scientific papers note that the combination of geospatial data with machine learning methods allows to improve the accuracy of

object classification, prediction of territory changes and simulation of spatial processes.

A separate area of research is devoted to the application of artificial intelligence for the analysis of remote sensing data and three-dimensional modeling of the area. Scientists note the effectiveness of neural networks, convolutional models (CNNs) and transformers for automatic object recognition, digital terrain model building and LiDAR data processing. Such approaches contribute to increasing the accuracy of geodetic measurements and reducing the time of work.

Modern research also places considerable emphasis on the use of large language models and generative artificial intelligence in the GIS environment. Scientists are considering the concept of «autonomous GIS», in which artificial intelligence is able to independently form and perform geospatial analytical processes, search for data, process them and visualize results. This opens up new opportunities for automation of geodetic surveys and decision support [3].

In addition, modern review studies demonstrate the active development of the areas of integration of generative artificial intelligence into cartography and GIS. The main areas of application are automated map creation, analysis of spatial patterns, processing of natural language user requests and support for geospatial modeling.

Despite a significant number of scientific works, the issues of complex integration of artificial intelligence and GIS technologies in geodesy remain insufficiently researched. The problems of ensuring the accuracy of models, interpreting the results of algorithms, processing heterogeneous geospatial data and introducing intelligent systems into the practice of geodetic works are especially relevant. This necessitates further research in this area [6].

The purpose of this study. there is an assessment of the possibilities of integrating artificial intelligence technologies and geoinformation systems in the field of geodesy, an analysis of modern approaches to the automation of geospatial data processing, as well as a determination of the advantages and prospects of using intelligent algorithms to increase the accuracy, efficiency and efficiency of geodetic works. Special attention is paid to the assessment of the possibilities of applying

machine learning methods and big data analysis in combination with GIS technologies to solve modern tasks of geodetic support.

Research materials and methods. The research was carried out using a complex of general scientific and special methods aimed at assessing the possibilities of integrating artificial intelligence technologies and geoinformation systems (GIS) in modern geodesy. Systematic, comparative and information-analytical approaches became the methodological basis of the work.

In the research process, the analysis and generalization of scientific publications, regulatory and technical documentation and modern practices of the application of artificial intelligence in geodesy, GIS, remote sensing of the Earth and cadastral activities were used. System analysis methods were used to assess the possibilities of AI and GIS integration, which made it possible to determine the main directions of using intelligent algorithms during geospatial data processing. The comparative method was used to compare traditional and modern approaches to the performance of geodetic works, as well as to evaluate their effectiveness based on indicators of accuracy, speed of information processing and level of automation.

Modern GIS platforms, technologies of remote sensing of the Earth, laser scanning (LiDAR), satellite navigation systems, unmanned aerial vehicles and machine learning algorithms, in particular convolutional neural networks (CNN), used for analysis and automated processing of geospatial data, are considered as the instrumental basis of the research. The generalization of the obtained results was carried out using the methods of logical analysis, synthesis and systematization, which made it possible to determine promising directions for the development of intelligent geoinformation systems in geodesy.

Of particular importance is the application of deep learning technologies for processing remote sensing data of the Earth. Thanks to the use of convolutional neural networks (CNNs), it became possible to automatically detect objects in high-resolution images. Such methods far outperform traditional approaches in processing speed and accuracy of results. In addition, AI algorithms can detect patterns that are difficult or impossible to identify using traditional analysis techniques [4].

An important area of AI and GIS integration is laser scanning data processing (LiDAR). LiDAR technology provides high-precision three-dimensional information about the Earth's surface and objects located on it. However, the volumes of such data can reach hundreds of gigabytes or even terabytes. The use of machine learning algorithms allows you to automate the process of classifying point clouds, highlighting buildings, vegetation, transport networks and other elements. This significantly reduces information processing time and increases the efficiency of geodetic surveys.

Equally important is the use of artificial intelligence to create and update digital terrain models. Traditionally, the formation of digital terrain models required significant time and manual data processing. Modern machine learning algorithms are able to automatically analyze spatial information, eliminate measurement errors and form high-precision digital models. Such solutions are widely used during the design of engineering structures, territorial planning, monitoring of natural resources and risk assessment of emergency situations.

Artificial intelligence in GIS also contributes to the development of predictive analysis of geospatial processes. Thanks to the use of historical data and machine learning methods, land use changes, development of urbanized areas, erosion processes, flooding risks and other natural phenomena can be predicted. It enables public administrations and enterprises to make more informed decisions on land use and territorial planning [7].

Significant advantages are provided by the use of artificial intelligence technologies in cadastral activities. Automated systems can check cadastral data, identify inconsistencies between documents and the actual condition of land plots, analyze changes in land use boundaries and form recommendations for their clarification. This contributes to improving the quality of cadastral information and reducing the number of errors related to the human factor.

The use of unmanned aerial vehicles in combination with GIS and artificial intelligence deserves special attention. Drones allow you to quickly obtain highly accurate data about the state of territories, and AI algorithms ensure their automatic

processing. This approach is actively used to monitor construction, control the state of transport infrastructure, assess the consequences of natural disasters and conduct agriculture. The combination of these technologies makes it possible to obtain up-to-date information practically in real time [8].

Modern GIS platforms are increasingly incorporating artificial intelligence tools directly into their software complexes. This allows users to perform complex spatial analysis without the need for in-depth knowledge in the field of programming or machine learning. Intelligent modules can automatically select analysis methods, identify spatial patterns and generate analytical reports. As a result, GISs are being converted from data visualization tools to comprehensive decision support systems.

Despite the numerous advantages of artificial intelligence and GIS technologies in geodesy, it is accompanied by a number of problems. First of all, this concerns the quality of the output data, which directly depends on the accuracy of machine learning algorithms. In addition, there are issues of interpretation of the results obtained with the help of complex neural networks, as well as the need to ensure cyber security and protection of geospatial information. An important challenge remains the need for highly qualified specialists with knowledge both in the field of geodesy and GIS, as well as in the field of artificial intelligence.

Prospects for the further development of AI and GIS integration are related to the improvement of deep learning algorithms, the development of cloud technologies, the use of large geospatial data and the creation of intelligent geoinformation platforms of a new generation. The level of automation of geodetic processes is expected to increase substantially in the coming years, and the role of artificial intelligence in spatial data analysis and management will become determinant [9].

Research results and their discussion. In the course of the study, it was established that the integration of artificial intelligence and GIS technologies in geodesy significantly increases the efficiency of spatial data processing and analysis. The use of machine learning algorithms allows automation of area classification, object recognition in aerial and satellite imagery, and improves the accuracy of spatial modelling. GIS systems in combination with AI provide quick updating of

cartographic information and forecasting of changes in terrain and land use. It has also been proven that such technologies significantly reduce the time of geodetic work and reduce the influence of the human factor on the measurement results. The obtained results confirm the feasibility of further implementation of integrated AI and GIS solutions in the practice of geodetic research.

Table 1

Main areas of AI and GIS integration in geodesy

Direction of application	GIS functions	The role of AI	Integration result
Spatial data processing	Mapping, spatial analysis	Machine learning	Automatic detection of patterns in data
Processing of satellite images	Remote sensing of the Earth	Neural networks	Improving the accuracy of object classification
3D modeling of the area	Construction of digital relief models (DEM)	Deep Learning	Automatic creation of 3D models
Deformation monitoring	Spatial monitoring	Time series analytics	Detection of surface changes in real time

The table displays the main areas of integration of artificial intelligence and GIS technologies in geodesy, showing the interaction between the functions of geoinformation systems and AI methods and the obtained results. In particular, in spatial data processing, GIS provides mapping and spatial analysis, and machine learning algorithms allow automatic detection of patterns in geodata arrays. In the field of satellite image processing, GIS is used for remote sensing of the Earth, while neural networks increase the accuracy of object classification in images. During 3 D terrain modeling, GIS forms digital terrain models (DEMs), and deep learning techniques provide automatic creation of accurate 3 D models. In the direction of strain monitoring, GIS performs spatial analysis of changes, and AI-based time series analytics allow near-real-time detection of surface changes. Thus, the integration of AI and GIS significantly increases the accuracy, automation and efficiency of geodetic research.

Table 2

Comparison of traditional and AI-GIS methods in geodesy

Criterion	Traditional GIS methods	GIS + AI
Processing speed	Low /medium	High
Analysis accuracy	Depends on the operator	Higher thanks to learning algorithms
Automation	Limited	High level of automation
Working with big data	Complicated	Effective (Big Data approach)
Adaptability of models	Low	Self-learning systems

The table compares traditional GIS methods and an approach integrating GIS with artificial intelligence in geodesy against basic performance criteria. In particular, it is shown that traditional methods are characterized by a lower or average speed of data processing, while in GIS + AI systems it is significantly higher due to process automation. The accuracy of the analysis in classical approaches depends largely on the operator's experience, while the use of machine learning algorithms provides consistently higher results. The level of automation also differs significantly: in traditional GIS, it is limited, while integration with AI allows most operations to be performed automatically. When working with large volumes of data, traditional methods face difficulties, while AI-GIS systems effectively apply the Big Data approach. Furthermore, the adaptability of models in classical systems is low, whereas when combined with AI they are capable of self-learning and continuous improvement [10].

Table 3

Practical results of the implementation of AI + GIS in geodesy

Scope	Example of use	Effect achieved	Limitations
Cadastral works	Automatic land inventory	Reduction of processing time to 40–60%	Need for quality data
Construction	Control of deformations of buildings	Early identification of risks	High implementation cost
Environmental	Analysis of	More accurate	Dependence on

monitoring	landscape changes	forecasting of changes	satellite data
Urban planning	Smart City modeling	Infrastructure optimization	Complexity of systems integration

The table demonstrates the practical results of implementing the integration of artificial intelligence and GIS technologies in various fields of geodesy, as well as the associated effects and limitations. In cadastral works, the use of AI allows you to automate land inventory and reduce data processing time by 40–60%, but efficiency depends on the quality of the original information. In construction, such technologies are used to control deformations of structures, which ensures early detection of potential risks, although implementation remains expensive. In environmental monitoring, integrated systems are used to analyse landscape changes, which increases forecasting accuracy, but depends to a large extent on the availability of satellite data. Thus, the results confirm the high efficiency of technologies in the presence of appropriate infrastructure and quality data.

Conclusions and prospects. As a result of the analysis, it was established that the integration of artificial intelligence (AI) and geoinformation systems (GIS) in geodesy is one of the key areas of development of modern geospatial technologies. Combining the analytical capabilities of GIS with machine learning and deep learning algorithms provides a significant increase in the efficiency of spatial data processing, analysis and interpretation.

It has been established that the use of artificial intelligence technologies allows to significantly reduce the processing time of large arrays of geodata, to automate the processes of recognition and classification of terrain objects, as well as to increase the accuracy of the results of geodetic measurements. Neural networks are especially effective in processing Earth remote sensing data and aerial photographs.

An important result is the confirmation that the integration of AI and GIS technologies ensures the transition from traditional methods of geospatial analysis to intelligent automated decision support systems. Such systems are able not only to process data, but also to detect hidden spatial patterns and predict changes in territories.

At the same time, a number of problems have been identified that restrain the full implementation of these technologies in geodetic practice. These include the dependence of the quality of results on the initial data, the complexity of interpreting artificial intelligence models, the need for highly qualified specialists, and the issue of integrating heterogeneous geospatial systems.

Prospects for further development are related to the improvement of machine learning algorithms, the introduction of cloud GIS platforms, the use of large geospatial data (Big GeoData) and the creation of intelligent geoinformation systems of the new generation. Such technologies are expected to become the basis of automated geodesy of the future.

Thus, the integration of artificial intelligence and GIS technologies is an important step in the development of modern geodesy, which ensures an increase in the accuracy, efficiency and efficiency of geospatial research.

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ІНТЕГРАЦІЯ ШТУЧНОГО ІНТЕЛЕКТУ ТА ГІС-ТЕХНОЛОГІЙ У ГЕОДЕЗІЮ

Анотація. *Інтеграція технологій штучного інтелекту та геоінформаційних систем (GIS) є одним із ключових напрямів розвитку сучасної геодезичної науки та практики. Поєднання інструментів просторового аналізу з інтелектуальними алгоритмами створює нові можливості для автоматизації збору, опрацювання, аналізу та представлення геопросторової інформації. Це забезпечує підвищення точності геодезичних вимірювань, прискорення виконання робіт і покращення якості управлінських рішень.*

Сучасні геодезичні дослідження базуються на використанні значних масивів просторових даних, що надходять із глобальних навігаційних супутникових систем, безпілотних літальних апаратів, засобів лазерного сканування та дистанційного зондування Землі. Обробка такої інформації традиційними методами потребує значних часових і людських ресурсів. Використання технологій штучного інтелекту дозволяє автоматизувати пошук закономірностей, класифікацію об'єктів та виконання складного аналізу даних із високим рівнем точності та швидкодії.

Особливу роль у розвитку сучасної геодезії відіграють методи машинного навчання та нейронні мережі, які забезпечують автоматичне розпізнавання об'єктів на супутникових і аерофотознімках. Їх застосування істотно спрощує процес створення цифрових карт, актуалізації геопросторових баз даних та спостереження за змінами земної поверхні. Це дає змогу оперативно отримувати достовірні відомості про забудову територій, стан земельних ресурсів і перебіг природних процесів.

Геоінформаційні системи забезпечують накопичення, зберігання, обробку та візуалізацію просторової інформації, а застосування штучного інтелекту значно розширює можливості її аналізу та прогнозування. Поєднання цих технологій сприяє створенню інтелектуальних геоінформаційних систем, здатних автоматично виявляти тенденції розвитку територій, оцінювати потенційні ризики та прогнозувати зміни природного середовища.

Одним із перспективних напрямів використання штучного інтелекту в геодезії є автоматизація обробки результатів геодезичних вимірювань, аналіз

геопросторової інформації, побудова цифрових моделей рельєфу та оновлення кадастрових даних. Алгоритми машинного навчання забезпечують більш точне визначення координат, автоматичне розпізнавання просторових об'єктів і своєчасне виявлення змін у геодезичних матеріалах. Окремим напрямом є земельний моніторинг, у межах якого технології штучного інтелекту застосовуються для оцінювання змін землекористування, контролю стану земельних ресурсів та інформаційної підтримки процесу управління територіями.

Вагомі можливості відкриває використання інтелектуальних алгоритмів під час моніторингу інженерних споруд, транспортних мереж і природних комплексів. Аналізуючи геодезичні спостереження в режимі реального часу, такі системи можуть прогнозувати деформаційні процеси, своєчасно виявляти потенційно небезпечні ділянки та попереджати про можливі аварійні ситуації, що має важливе значення для забезпечення безпечної експлуатації критичної інфраструктури.

Інтеграція штучного інтелекту та GIS-технологій знаходить широке застосування й у сфері міського планування та реалізації концепцій «розумного міста». Геопросторовий аналіз дозволяє оптимізувати транспортну інфраструктуру, планувати розвиток інженерних комунікацій, а також оцінювати екологічні наслідки урбанізаційних процесів. Це забезпечує органи державного управління та місцевого самоврядування сучасними інструментами для обґрунтованого планування розвитку територій.

Разом із численними перевагами впровадження технологій штучного інтелекту в геодезичну діяльність супроводжується необхідністю вирішення питань забезпечення якості вихідних даних, інформаційної безпеки та вдосконалення алгоритмів аналізу. Подальші наукові дослідження зосереджуються на підвищенні точності моделей машинного навчання, розвитку автоматизованих технологій обробки геопросторової інформації та створенні нових інтелектуальних сервісів для геодезичної галузі.

Отже, інтеграція технологій штучного інтелекту та геоінформаційних систем є важливою складовою цифрової трансформації сучасної геодезії. Їх комплексне використання забезпечує підвищення ефективності геодезичних робіт, покращення якості аналізу просторових даних, розширення можливостей моніторингу територій та сприяє розвитку сучасних підходів до управління земельними ресурсами й інфраструктурними об'єктами.

***Ключові слова**: інтеграція, штучний інтелект, GIS-технології, геодезія, геопросторові дані, машинне навчання, нейронні мережі, цифрові карти, моніторинг територій.*