UDC 528.4:004.8+303.732.4

INTELLIGENT TECHNOLOGIES IN THE EVOLUTION OF ELECTRONIC GEODETIC INSTRUMENTS: CONCEPTUAL FOUNDATION FOR THE INTEGRATION OF ARTIFICIAL INTELLIGENCE INTO SPATIAL MANAGEMENT SYSTEMS AND THE GEOINFORMATION ENVIRONMENT

O.S. Malashchuk, *Candidate of Economic Sciences, Associate Professor*
E-mail: osmalashcuk@gmail.com
Odesa State Agrarian University
T.V. Movchan, *Candidate of Economic Sciences, Associate Professor*
E-mail: mov4an.tata@gmail.com
Odesa State Agrarian University
T.A. Rozhi, *Lecturer*
E-mail: tomas.rozhi.94@gmail.com
Pavlo Tychyna Uman State Pedagogical University

Abstract. *The article explores the issue of intellectualisation of electronic geodetic instruments in the context of spatial management systems, emphasising the transformation from automated procedures to adaptive self-learning technological solutions with the integration of digital ethics principles. An algorithmic analysis is implemented using the extended Kalman filter (EKF) and recurrent Long Short-Term Memory (LSTM) neural network architectures for adaptive filtering of information flows, as well as geospatial statistics and GIS visualisation methods for verifying coordinate consistency. The obtained scientific results indicate that intellectualisation determines the transformation to cognitive systems with sensor integration (GNSS, IMU, EDM), achieving millimetre accuracy using artificial intelligence algorithms – particularly EKF and LSTM – for predictive modelling of errors and auto-correction. It was established that cloud infrastructure and interoperability with GIS platforms (ArcGIS, QGIS) form a unified digital* *environment with data validation mechanisms, which increases metrological stability and ethical accountability of systems.*

The practical significance of the study is determined by the improvement of public administration systems, in particular urban planning, land cadastral accounting and infrastructure monitoring, where intelligent devices provide real-time data updates and preventive risk management. The study contributes to increasing the transparency of state registers through digital measurement passports, reducing errors and legal conflicts in the geoinformation environment. Prospects for further scientific exploration include the development of ethical standards for artificial intelligence in geodesy and integration with Internet of Things (IoT) technologies to establish global monitoring networks.

Keywords: intellectualisation, geodetic instruments, sensor integration, artificial intelligence, geographic information systems, public spatial management.

Problem Statement. The intellectualisation of electronic geodetic instruments is a priority vector of the evolution of contemporary geodetic science, reflecting the global trend of transformation from automated measurement processes to the development of adaptive, self-learning and ethically balanced technological solutions. Within the framework of the digital transformation of the public spatial management system in Ukraine, the introduction of intelligent tacheometric complexes, global navigation satellite systems (GNSS) and laser scanning devices into state geoinformation infrastructures forms the foundation for creating a unified digital environment of reliability, where each coordinate position has a verified origin, and each measurement act has metrological validity and legal relevance. The scientific and practical significance of the study is determined by the need to enhance the accuracy, transparency and reproducibility of spatial data used in urban planning, land cadastral accounting, infrastructure monitoring and environmental monitoring.

Review of Recent Research and Publications. In the scientific discourse, there is a clear trend towards the convergence of electronic geodetic technologies with the methodology of artificial intelligence, machine learning and sensor integration. Scholarly investigations by L. Kovalenko [2], M. Voichik et al. [16] emphasise the transformation from traditional automated tools to cognitive systems capable of autonomously adapting measurement parameters and implementing autocalibration in real time. The publications of A. Batrakova et al. [1] and A. Stefanov [15] reveal the potential of digital geodetic systems in ensuring spatial stability and precision in the construction of engineering objects, as well as in the generation of digital terrain models based on complex measurement data. Researchers O, Stupen et al. [6] emphasise the importance of implementing geoinformation technologies in public administration, especially in the context of cadastral monitoring and land management. The works of F. Bajrami Lubishi, M. Lubishtani, [10], M. Sehnal [13] present approaches to the automation of geodetic control processes using cloud services and information validation modules. The totality of the presented scientific positions confirms that the intellectualisation of geodetic instruments is a determining factor in optimising public spatial management systems.

The aim of the study is to determine the current processes of intellectualization within new generations of electronic geodetic equipment for assessing the state of the geoinformation environment, are aimed at shaping an integrated technological, algorithmic and ethical model of their functioning.

Materials and Methods. The methodological framework of the study is based on systemic, structural-functional and cyber-physical conceptual approaches to studying the processes of intellectualisation of electronic geodetic instruments in the context of public spatial management. The work implements a comprehensive application of theoretical and empirical methods: analytical – to systematise the trends in the evolution of sensor technologies and artificial intelligence algorithms; modelling – to design architectural schemes of integrated geodetic systems with sensor integration; metrological experiment – for assessing the precision and stability of measurements in variable environmental conditions. An algorithmic analysis was conducted to investigate adaptive filtering of information flows and predictive modelling of sensor drift using the extended Kalman filter (EKF) and recurrent Long Short-Term Memory neural networks (LSTM). Additionally, geospatial statistics and

GIS visualisation methods were applied to verify coordinate consistency in the process of integrating measuring devices with geoinformation platforms.

Comparative analysis methods were used to evaluate the technical characteristics of different generations of electronic total stations, digital levels and GNSS receivers to determine the level of their adaptability to automated control conditions. Cloud analytics tools were utilised to model the processes of transmitting and storing geodata in real time, which made it possible to assess the degree of integration compatibility between devices and public geoportals. The expert evaluation method was applied to determine the importance of intelligent modules in increasing measurement accuracy and reducing positioning errors.

Results and Discussion. The intellectualisation of geodetic instruments is a logical stage in the evolution of measurement technologies, when the transition from optical to electronic systems no longer meets the requirements for accuracy, speed and cognitive autonomy of spatial data collection processes. Consequently, there is a need to create sensor complexes capable of self-learning, contextual adaptation and interaction with the environment in real time. Modern electronic total stations, laser scanners and GNSS receivers embody a new paradigm of geodetic measurement, where accuracy has not only become a function of hardware stability, but also the result of algorithmic thinking, which forms a system of prediction, correction and analysis of errors at a level previously available only to humans [3, p. 19].

The essence of the transition lies in the integration of artificial intelligence, machine learning and sensor fusion into the architecture of the geodetic device, enabling them not merely to collect information, but also to interpret it within the context of a complex multifactorial reality. Deep learning algorithms, in particular neural networks with error propagation, are increasingly utilised to model deviations in the operation of light rangefinders, to predict meteorological influences or to compensate for temperature deformations. Sensor fusion, as a technological platform for combining data from various sources – a laser rangefinder, IMU, GNSS module and optoelectronic tracker – provides the instrument with intrinsic self-correction capabilities, thereby increasing metrological stability even in unstable field conditions. Sensor integration in new generation geodetic instruments is polystructural in nature, encompassing the interaction of laser rangefinders, GNSS receivers, optoelectronic guidance systems, inertial modules (IMU), and MEMS sensors of microscopic oscillations, temperature and vibrations [14, p. 149-150]. Each of these sensors does not function in isolation, but within the framework of a sensor coupling system, where information from different channels is combined to create an integrated adaptive measuring environment.

Within the architecture of intelligent systems, a unique mechanism of dynamic data consistency is formed, when each sensor has a reliability weight coefficient that changes depending on the measurement environment. For instance, in a weak GNSS signal, data from inertial sensors and an optical tracker become more significant, while in open terrain the main role is played by satellite reference. These technical solutions are implemented in Leica Nova and Trimble S-series systems and become the basis for achieving accuracy in the millimetre range even under difficult weather conditions or limited access to base stations (Table 1) [9].

Table 1

Sensor integration and functional modules of intelligent geodetic systems

Sensor / Module Type	Key function	Specifications	System interaction	Application examples
Laser Rangefinder (EDM)	Measurement of the distance to the target using the principle of phase shift or momentum	Range: up to 5 km per prism; accuracy: ±(1–2) mm	Synchronises with GNSS and IMU to compensate for tilt error	Monitoring of deformations of structures, surveying of quarries
GNSS Receiver (RTK/PPP)	Determination of coordinates from global satellite systems	RTK accuracy: 8–10 mm; initialisation time: <5 s	Provides absolute geospatial system reference	Geodynamic observations, cadastral works
Opto-Electronic Guidance System	Automatic detection and tracking of the aiming target	Rotation speed: up to 100°/s; pointing accuracy: 1"	Synchronises with EDM and IMU; operates in closed loop with autotracker	Monitoring works of building structures

IMU (Inertial Measurement Unit)	Determination of angular accelerations, inclinations, vibrations	3-axis gyroscopes, 3-axis accelerometers; frequency 200 Hz	Performs vibration compensation and dynamic stabilisation	Automated total station, works in motion
MEMS Climate Sensors	Control of temperature, pressure, humidity	Temperature accuracy ±0.1°C; update rate 1 Hz	Transmits correction factors for EDM and optical systems	Autocorrection of refraction in rangefinder measurements
Camera / Video Tracker	Visual recognition of the target and the environment	12–24 MP resolution; AI frame processing	Integrates with computer vision systems; provides auto-tracking	3D scanning, photogrammetry, VR visualisation

Compiled by the authors based on [9, 14]

Algorithmic support of intelligent geodetic systems is a central component, as it is this element that transforms the multidimensional data stream into a structured model of space. Such devices use a combination of adaptive filtering algorithms, correlation analysis, machine learning and neural network models for drift prediction. For instance, the Kalman filter in its extended form (EKF) is used to synchronise GNSS and IMU, and combines inertial measurements with satellite coordinates, which reduces the position error to a few millimetres [16]. Neural networks based on LSTM (Long Short-Term Memory), implemented within the UTCN coordinate framework, are used to predict the behaviour of sensors over time, particularly for compensating the drift of laser rangefinders or temperature deviations in photodetectors (Figure 1).

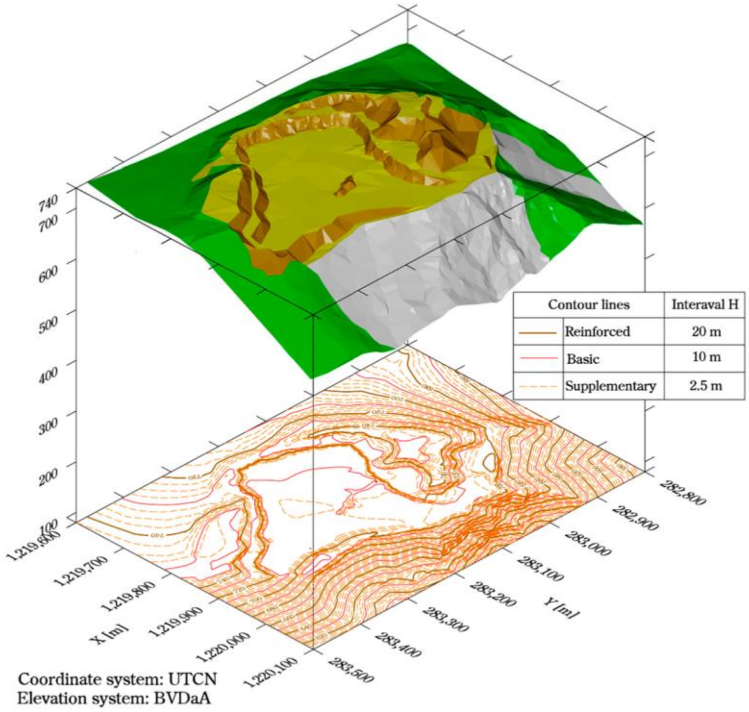

Figure 1. Three-dimensional terrain model with elevation contours in the UTCN coordinate system

Compiled by the authors based on [16]

The Topcon DS and Trimble S8/S9 series devices implement intelligent self-tuning algorithms that analyse environmental parameters and optimise the measurement mode in real time: with increased humidity, the laser power automatically increases, and with intense solar radiation, the spectral compensation mode is activated.

The AI system built into the control module uses machine algorithms based on a decision tree to classify observation conditions, thereby reducing the number of incorrect observations. An important role in the functioning of intelligent total stations is played by self-diagnostic and calibration modules that constantly monitor the geometric stability of the device, detect abnormal base oscillations and compensate for them without stopping the measurement process [4, p. 82]. Leica Nova systems implement a three-level self-diagnostic scheme: at the first level, the internal tilt sensor is checked at the second, the stability of the optical axis is assessed, and at the third, the electronic horizon is corrected according to IMU data.

This enables the maintenance of metrological accuracy within ±1" without the need for periodic manual verification (Table 2).

Table 2

Algorithmic support and artificial intelligence in intelligent geodetic spatial support systems

Algorithmic support component	Key functions	Implemented technologies	Results/Effects	Examples of systems
Adaptive signal filtering	Noise smoothing, measurement error compensation	Extended Kalman Filter (EKF), Unscented KF	Increase in GNSS+IMU positioning accuracy up to 5 mm	Trimble S9, Leica Nova TS60
Machine learning for drift prediction	Detection of systematic changes in sensor operation	LSTM, Random Forest	Automatic compensation for temperature and mechanical shifts	Topcon DS, FOIF RTS005A
Sensor fusion and correlation processing	Combining data from different sensors	Bayesian Fusion, Cross-Correlation Model	Eliminate discrepancies between EDM, GNSS and IMU	Leica GS18, Trimble SX10
Neural network control of device stability	Determination of deviations in component operation	CNN, Decision Tree Ensemble	Self-adjustment of system geometry in real time	FOIF RTS005, Leica Nova
Automatic target recognition	Identification of targets by visual features	Computer Vision, YOLOv8	Automatic guidance with an accuracy of 0.5"	Trimble S8, Leica TS60
Prediction of observation conditions	Analysis of the impact of the environment on measurements	Time Series Forecasting, Gaussian Process	Automatic optimisation of laser power and optics parameters	Topcon DS, Trimble SX12

Compiled by the authors based on [1, 7]

The intellectualisation of devices is impossible without a developed cloud infrastructure that provides collection, storage and exchange of spatial data between field devices and central servers. New generation geodetic devices have built-in wireless communication modules (LTE/5G, Wi-Fi, Bluetooth 5.2), which allow real-time transmission of observation results to public geoportals integrated with state cadastre systems, BIM models and spatial planning platforms. Through API interfaces, devices interact with cloud services such as Trimble Connect, Leica Infinity, Topcon MAGNET or FOIF Cloud, where automatic archiving, construction of 3D models and creation of digital twins of the terrain are performed [11, p. 40].

These types of services implement mechanisms for the joint work of several operators, when the measurement results from different devices are automatically combined into a single database, and spatial validation algorithms check the consistency of coordinates, determining the degree of trust in each point. This creates the basis for public infrastructure monitoring systems, where data is updated in real time without the need for physical presence of specialists at the observation site. Cloud architectures also create opportunities for the implementation of digital ethics in measurement processes: each measurement record is stored with a digital signature of the operator, a time stamp and a calibration log of the instrument, which guarantees the reproducibility and reliability of the results [12]. In the future, these data will form “ethical passports” of geodetic operations, where each coordinate will have a history of its verification, correction and use [2].

Within the framework of geoinformation interaction, compatibility between intelligent total stations, laser scanners, unmanned aerial systems (UAV-GIS) and data processing platforms such as ArcGIS, QGIS, MapInfo, Global Mapper or national geoportals plays a key role. Thanks to the support of open exchange formats: GeoJSON, WMS/WFS, GML, CityGML, LAS, instant upload of field measurements to central repositories is ensured, where they undergo automatic verification for consistency with existing cadastral and topographic databases [8, p. 101]. A feature of intelligent systems is that they not only transmit geodata but also accompany them with a full package of technical information – calibration metadata, history of device parameter changes, validation reports and digital signatures of the operator (Figure 2).

Figure 2. Fragment of an aerial photograph with the outlined geodetic survey area of an infrastructure facility

Compiled by the authors based on [13]

Modern geographic information systems ArcGIS Pro or QGIS with the QField module already support direct connection to Leica, Trimble or FOIF field instruments operating in RTK mode. In this case, the coordinates obtained by the instrument are synchronised with the central database via MQTT or REST API protocols, which allows not only to transfer data, but also to receive updates on changes in the contours of land plots, transport infrastructure or geodynamic processes [5].

Cadastral registration, which traditionally relied on discrete surveys, is gradually transforming into a continuous monitoring process in the digital age, where each measurement has a confirmed trace of origin. Intelligent geodetic systems provide automated data traceability by generating unique identifiers for each measurement, which are associated with the operator's electronic signature, GNSS coordinates, fixation time and instrument software version. Within state cadastral registers, these metadata are integrated with electronic measurement logs, enabling the automatic confirmation of survey results and preventing any possibility of data manipulation.

Intelligent devices are integrated into the IoT network form multi-point observation systems, in which each sensor transmits data on the micro-displacement of the object, temperature deformations or vibrational disturbances. Combined with a geoinformation platform, these data are automatically analysed by machine learning algorithms that recognise anomalous changes and warn about the risks of soil destruction or subsidence. For public administrations, this means the possibility of moving from reactive to preventive infrastructure risk management, when decisions are made based on continuous spatial analysis, rather than ex post facto.

To ensure the reproducibility and metrological consistency of results within integrated systems, the principle of multi-level data validation is used, involving automatic verification of each measurement at the sensor, device, geoinformation base and state register levels. At the first level, the internal consistency of the data is checked, including the correspondence between measured coordinates, angles and distances. At the second level, the system compares data with previous observations, recording deviations above permissible standards [15]. At the third level, verification is performed with external databases (for example, the State Land Cadastre, where automatic algorithms establish the correspondence of land plot contours and attribute data (Table 3).

Table 3

Integration of intelligent geodetic devices into public spatial management systems (compiled by the authors)

Scope	Type of integration	Key tools and technologies	Algorithmic mechanisms	Expected results for public administration
Spatial planning	Integration of data from devices into GIS layers of urban planning models	ArcGIS Pro, QGIS, CityGML, BIM interfaces	Spatial coordinate matching, topological conflict analysis, traffic flow simulation	Operational updating of urban planning documents, increasing the accuracy of forecasting the development of territories
Cadastral registration	Transfer of measurements with a digital signature to state cadastral databases	GNSS-RTK + REST API integration with the State Land Cadastre	Automatic metadata generation, digital signature verification, measurement tracing	Reducing the number of errors in cadastral records, increasing trust in geodata

Infrastructure monitoring	Continuous monitoring of the condition of objects via IoT networks	Trimble Monitoring, Leica GeoMoS, FOIF Cloud	Rapid detection, predictive analytics, automatic notifications	Preventive management of destruction risks, optimising repair work
Environmental monitoring	Integration of geodata from devices and sensors into landscape monitoring systems	UAV-GIS, satellite imagery, OpenDataHub	Multispectral analysis, correlation with climate models	Assessment of anthropogenic impact, supporting sustainable land use decisions
Public visualisation and transparency	Open geoportals for citizens and local governments	INSPIRE Geoportal, National Geoinformation Infrastructure	API access to layers, version control, digital data certification	Increasing transparency of management processes, public control of spatial decisions
Legal and metrological validation	Verification of data in state registers for compliance with ISO 191xx standards	Blockchain-tracing, device certification	Multi-level verification, calibration control	Increasing the reliability of spatial records, reducing the level of technical risks

Compiled by the authors

One of the most complex yet most valuable components of integration is ensuring interoperability between systems of different levels of governance: those of territorial communities and those at the state level. From the point of view of public administration methodology, the integration of intelligent geodetic devices radically changes the very logic of making managerial decisions: if previously analytics were formed on the basis of reports and periodic surveys, today the manager works with streaming data that are updated every minute, allowing the application of the principles of "evidence-based policy" in real time [3]. This means that decisions on updating the boundaries of a land plot, repairing a bridge or regulating development can be made based on data collected by devices only minutes earlier, which significantly enhances the efficiency and responsibility of public administration.

In conclusion, it should be emphasised that the comprehensive integration of intellectualised geodetic systems into the structure of public spatial management initiates the formation of a new paradigm of spatial verification, within which each metric unit, coordinate value and boundary line acquire the status of digitally validated elements of spatial knowledge. Such a system not only optimises the quality of management decisions based on spatial data but also ensures the public legitimacy of state information registers, creating a methodological basis for sustainable development, where digital technologies and geospatial measurements function as an integrated system of cognition, verification and forecasting.

Conclusions and Recommendations. It is determined that the process of intellectualisation of electronic geodetic instruments determines the formation of a new technical and methodological concept of spatial measurements, within which the precision and validity of the results are conditioned not solely by the technical characteristics of the equipment, but also by the system's potential for cognitive transformation and algorithmic self-correction. Progress in the field of sensor integration, which involves the combination of GNSS satellite receivers, laser measuring devices, inertial navigation units and optoelectronic paths, enables autonomous coordination of information flows in real time, thereby reducing measurement deviations even under adverse field conditions.

It is argued that the algorithmic basis is a central component of intellectualised geodetic systems, since it ensures the integration of sensor information into a unified digital representation of space and implements predictive modelling of errors, automatic calibration and self-identification of measuring devices. The use of adaptive computational methods – Kalman filtering, Bayesian estimation, recurrent neural network architectures such as LSTM – ensures the achievement of millimetre positioning accuracy, stabilisation of the functioning of systems in the mode of continuous observation, and the mitigation of exogenous factors.

It is substantiated that the introduction of intellectualised geodetic instruments into public spatial management systems ensures the formation of an integrated information circuit, within which geospatial data are transformed into legally relevant, verified and ethically regulated units of spatial knowledge. By connecting measuring complexes to geoinformation platforms and cloud services, automatic data traceability, their multi-level verification and synchronisation with state cadastral systems are ensured.

References

1. Batrakova, A. H., Dorozhko, Ye. V., & Yemets, V. A. (2021). Osoblyvosti pobudovy tsyfrovoi modeli reliefu za rezultatamy heodezychnoi ziomky mistsevastsi [Features of constructing a digital terrain model based on the results of geodetic surveying of the area]. Komunalne hospodarstvo mist, 1(161), 104–108. https://doi.org/10.33042/2522-1809-2021-1-161-104-108

2. Kovalenko, L. O. (2022). Heodezychne zabezpechennia budivnytstva inzhenernykh sporud [Geodetic support for the construction of engineering structures]. Komunalne hospodarstvo mist. Seriia: informatsiini tekhnolohii ta inzheneriia, 3(170), 223–227. https://doi.org/10.33042/2522-1809-2022-3-170-223-227

3. Makedon, V. V., & Bailova, O. O. (2023). Planuvannia i orhanizatsiia vprovadzhennia tsyfrovykh tekhnolohii v diialnist promyslovykh pidpryiemstv [Planning and organizing the implementation of digital technologies in the activities of industrial enterprises]. Naukovyi visnyk Khersonskoho derzhavnoho universytetu. Seriia "Ekonomichni nauky", 47, 16–26. https://doi.org/10.32999/ksu2307-8030/2023-47-3

4. Makedon, V. V., Kholod, O. H., & Yarmolenko, L. I. (2023). Model otsinky konkurentospromozhnosti vysokotekhnolohichnykh pidpryiemstv na zasadakh formuvannia kliuchovykh kompetentsii [Model for assessing the competitiveness of high-tech enterprises based on the formation of key competences]. Akademichnyi ohliad, 2(59), 75–89. https://doi.org/10.32342/2074-5354-2023-2-59-5

5. Rybina, O. I. (2025). Intehrovana model ISLA yak vidpovid na vyklyky suchasnoi zemelnoi polityky Ukrainy [Integrated ISLA model as a response to the challenges of modern land policy of Ukraine]. Naukovi zapysky Lvivskoho universytetu biznesu ta prava. Seriia ekonomichna. Seriia yurydychna, 44, 416–423. https://doi.org/10.5281/zenodo.15532670

6. Stupen, O. I., Prokopenko, N. I., & Shevchuk, S. M. (2025). Tsyfrova transformatsiia systemy zemleustroiu: avtomatyzatsiia upravlinskykh protsesiv u sferi vykorystannia ta okhorony zemelnykh resursiv [Digital transformation of the land management system: automation of management processes in the field of land use

and protection]. Zbirnyk naukovykh prats Ukrainskoho derzhavnoho universytetu zaliznychnoho transportu, 212, 172–184. https://doi.org/10.18664/1994-7852.212.2025.336296

7. Sukhyi, P. O., Sabadash, V. I., & Darchuk, K. V. (2021). Suchasni elektronni heodezychni prylady: praktykum [Modern electronic geodetic instruments: Practicum]. Chernivtsi: Yurii Fedkovych Chernivtsi National University.

8. Tymchenko, S. I. (2024). Kontseptsiia tsyfrovizatsii dorozhnio-infrastrukturnykh proiektiv v Ukraini: vykorystannia heoinformatsiinykh tekhnolohii dlia pidvyshchennia efektyvnosti upravlinnia [The concept of digitalization of road infrastructure projects in Ukraine: using geoinformation technologies to improve management efficiency]. Upravlinnia rozvytkom skladnykh system, 60, 95–104. https://doi.org/10.32347/2412-9933.2024.60.95-104

9. Shevchuk, S. M., Domashenko, H. T., & Kuryshko, R. V. (2024). Heodezychnyi monitorynh pry rozrobtsi kompleksnykh planiv prostorovoho rozvytku [Geodetic monitoring in the development of integrated spatial development plans]. Heohrafiia ta turyzm, 31, 31–37. https://doi.org/10.17721/2308-135X.2024.76.31-37

10. Bajrami Lubishi, F., & Lubishtani, M. (2025). Advancing geodesy education: Innovative pedagogical approaches and integration into STEM curricula. STEM Education, 5(2), 229-249. https://doi.org/10.3934/steme.2025012

11. Kukhar, M., Myronenko, M., Kobzan, S., & Masliy, L. (2023). Analysis of the main aspects of modern tools for solving geodetic problems. Sworld-Us Conference Proceedings, 1(usc16-01), 37-42. https://doi.org/10.30888/2709-2267.2023-16-01-043

12. Makedon, V., Myachin, V., Aloshyna, T., Cherniavska, I., & Karavan, N. (2025). Improving the readiness of enterprises to develop sustainable innovation strategies through fuzzy logic models. Economic Studies (Ikonomicheski Izsledvania), 34(5), 165-179. https://archive.econ-studies.iki.bas.bg/2025/2025_05/2025_05_09.pdf

13. Sehnal, M. (2025). The visibility challenge of geodesy. GIM International, 39(4), 20–21. https://www.gim-international.com/content/article/the-visibility-challenge-of-geodesy

14. Stadnikov, V., Likhva, N., Miroshnichenko, N., Kostiuk, V., & Dorozhko, Y. (2025). Exploring Geoinformation Technology Potential for Automating the Development and Maintenance of Digital Topographic Maps. African Journal of Applied Research, 11(1), 146-156. https://doi.org/10.26437/ajar.v11i1

15. Stefanova, A. (2025). Geodesy 4.0: Geodesy transformation via new technologies. Proceedings of the XII International Scientific Conference on Architecture and Civil Engineering (ArCivE 2025), Varna, Bulgaria, Vol. 5, 311-317.

16. Wójcik, M., Dmochowska-Dudek, K., & Tobiasz-Lis, P. (2021). Boosting the potential for GeoDesign: Digitalisation of the system of spatial planning as a trigger for smart rural development. Energies, 14(13), 3895. https://doi.org/10.3390/en14133895

О.С. Малащук, Т.В. Мовчан, Т.А. Рожі

ІНТЕЛЕКТУАЛЬНІ ТЕХНОЛОГІЇ В ЕВОЛЮЦІЇ ЕЛЕКТРОННИХ ГЕОДЕЗИЧНИХ ПРИЛАДІВ: КОНЦЕПТУАЛЬНІ ЗАСАДИ ІНТЕГРАЦІЇ ШТУЧНОГО ІНТЕЛЕКТУ В СИСТЕМИ ПРОСТОРОВОГО УПРАВЛІННЯ ТА ГЕОІНФОРМАЦІЙНОГО СЕРЕДОВИЩА

Анотація. *Стаття досліджує питання інтелектуалізації електронних геодезичних інструментів у контексті систем публічного просторового менеджменту, акцентуючи трансформацію від автоматизованих процедур до адаптивних самонавчальних технологічних рішень з інтеграцією принципів цифрової етики. Реалізовано алгоритмічний аналіз із залученням розширеного фільтра Калмана (EKF) та рекурентних нейромережевих архітектур довгої короткочасної пам'яті (LSTM) для адаптивної фільтрації інформаційних потоків, а також методів геопросторової статистики та ГІС-візуалізації для* *верифікації координатної консистентності. Отримані наукові результати свідчать, що інтелектуалізація детермінує трансформацію до когнітивних систем із сенсорною інтеграцією (GNSS, IMU, EDM), досягаючи міліметрової точності через застосування алгоритмів штучного інтелекту, зокрема EKF та LSTM, для прогностичного моделювання похибок та автокорекції. Встановлено, що хмарна інфраструктура та інтероперабельність із ГІС-платформами (ArcGIS, QGIS) формують уніфіковане цифрове середовище з механізмами валідації даних, що підвищує метрологічну стабільність та етичну підзвітність систем.*

Практична значущість дослідження визначається вдосконаленням систем публічного управління, зокрема урбаністичного планування, земельно-кадастрового обліку та інфраструктурного моніторингу, де інтелектуалізовані прилади забезпечують оновлення даних у режимі реального часу та превентивне управління ризиками. Дослідження сприяє підвищенню транспарентності державних реєстрів через цифрові паспорти вимірювань, редукуючи похибки та юридичні колізії в геоінформаційному середовищі. Перспективи подальших наукових розвідок передбачають розробку етичних стандартів для штучного інтелекту в геодезії та інтеграцію з технологіями Інтернету речей (IoT) для створення глобальних мереж моніторингу.

Ключові слова: *інтелектуалізація, геодезичні прилади, сенсорна інтеграція, штучний інтелект, геоінформаційні системи, публічне просторове управління.*