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THE ROLE AND PLACE OF GEOSPATIAL SUPPORT IN ENSURING THE RESILIENCE OF THE STATE BORDER PROTECTION SYSTEM UNDER HYBRID THREATS

The role and place of geospatial support in ensuring the resilience of the state border protection system of Ukraine under modern hybrid threats are substantiated. It is established that the dynamic security environment and the nature of non-conventional influences necessitate the transformation of traditional approaches to spatial support and their integration with geoinformation technologies.

It is determined that the resilience of the state border protection system largely depends on the quality, relevance, and accuracy of geospatial data, which form the basis for managerial and operational decision-making within the State Border Guard Service of Ukraine. The specifics of hybrid threats are examined, in which the geospatial factor plays a key role in ensuring situational awareness, forecasting adversary actions, and enabling timely response of border protection units.

Particular attention is paid to the processes of digitalization of geospatial support, including the implementation of digital terrain models and the use of geographic information systems for analyzing potential directions of state border violations. The scientific novelty of the study lies in clarifying the content and tasks of geospatial support under hybrid threats, while its practical significance is determined by the possibility of applying the obtained results to improve the regulatory framework of operational and service activities of the State Border Guard Service of Ukraine.

Keywords: *State Border Guard Service of Ukraine, national security, hybrid threats, resilience, geospatial support, geographic information systems, spatial data, situational awareness.*

Statement of the problem. The modern geopolitical security architecture is undergoing profound and irreversible transformations driven by large-scale armed aggression against Ukraine. Under these extreme conditions, the national security of the state directly depends on the adaptability and resilience of the state border protection and defense system [1]. The traditional paradigm of functioning of border guard units, which has been shaped for decades under conventional challenges of the previous century, is currently insufficient to counter asymmetric threats. In the context of hybrid warfare, where the boundary between peacetime law enforcement activities and high-intensity combat operations is becoming increasingly blurred, there is an urgent need for a comprehensive conceptual modernization of all elements of the state border protection system [4].

One of the most critical, yet often underestimated, components of this resilience is geospatial support. It is rapidly evolving from an auxiliary technical discipline (traditionally

associated with military topography) into a fundamental intellectual basis for command and control. Modern geospatial support serves as a core element that ensures the seamless integration of spatial data into the overall decision-making framework at all hierarchical levels [9].

The key challenge at the current stage lies in the qualitative transformation of the nature and temporal dynamics of threats at the border. Hybrid methods of influence – ranging from covert infiltration of sabotage and reconnaissance groups and the artificial instrumentalization of migration flows to complex cyberattacks on automated command and control systems require the State Border Guard Service of Ukraine to possess the capability for immediate preventive response. Achieving this is possible only with a critically high level of situational awareness among command personnel and staff [6]. However, the dynamic transformation of the terrain caused by intensive artillery shelling, remote mining of areas, and large-scale destruction of infrastructure continuously creates a situation of an "information vacuum". The insufficient timeliness of updating

geospatial data and the low level of integration of digital spatial models into network-centric command and control systems significantly limit the capabilities of border guard units. This leads to the emergence of "blind spots" that are effectively exploited by the adversary to achieve tactical and strategic objectives [8].

Analysis of recent research and publications.

Issues related to the organization of geospatial support and the strategic management of the state border are currently at the center of attention of leading military scholars and security sector practitioners. Fundamental aspects of military topography, including classical methods of terrain analysis and the use of cartographic materials in operational planning, are thoroughly examined in the works of R. S. Soika, A. M. Kulyk, and V. V. Artemenko [3]. Their studies have formed a solid theoretical foundation that has served for decades as the basis for the training of border guards; however, under the conditions of the modern high-tech battlefield, these approaches require substantial adaptation and integration into a unified geospatial support system. The comprehensive issues of national security and the nature of non-conventional conflicts have been thoroughly theoretically substantiated in the strategic works of V. P. Horbulin. The author emphasizes that success in future wars depends on technological superiority and the ability to rapidly transform defense institutions [1]. In this context, the transformation of the State Border Guard Service of Ukraine under the conditions of ongoing armed aggression and the search for innovative models of border protection are analyzed in detail in the scientific works of S. V. Deineko. In particular, emphasis is placed on the importance of transitioning to preventive methods of border protection based on accurate operational data [4]. The implementation of advanced technologies in military activities is of particular importance under modern conditions. The theoretical foundations of the functioning of geographic information systems (GIS) and their role in the national security and defense system have been thoroughly examined by O. V. Barladin [5]. Issues related to digital cartography and the transition to NATO standards in command and control are addressed in the work of Yu. M. Zharkov, who substantiates the critical necessity of abandoning outdated forms of topogeodetic support in favor of dynamic geospatial support [6]. Despite the significant body of research, there remains a need for further investigation of the mechanisms for integrating these systems directly into the state border

protection framework under conditions of active hostilities. The analysis of contemporary foreign scientific sources, including NATO publications and studies by J. Ash and M. Dodge, clearly indicates a shift in focus toward the concept of a "digital twin of the border". This concept involves the creation of a highly accurate virtual model of the border area, which is continuously updated in real time using artificial intelligence and machine learning algorithms [8].

Foreign scholarly discourse and current Alliance doctrinal documents consider military topography not as an isolated discipline, but as a component of a broader ecosystem of geospatial intelligence and support – Geospatial Intelligence (GEOINT). Such integration enhances the effectiveness of countering asymmetric threats by enabling the fusion of data from multiple sources (satellite imagery, UAV data, sensor networks) into a unified operational picture [7]. The implementation of such standards in the activities of the State Border Guard Service of Ukraine would make it possible to achieve interoperability with partner-country units and to enhance the overall resilience of the state border protection system. Despite the substantial body of theoretical research, a thorough analysis of professional publications over the past five years indicates the presence of a significant research gap. Most existing studies continue to treat geospatial support (often still referred to as topogeodetic support) as a static, auxiliary component operating within a relatively stable and predictable information environment.

Critical factors of modern high-tech confrontation remain insufficiently addressed in domestic research, including:

- the disruptive impact of the adversary's electronic warfare capabilities on the accuracy of satellite navigation signals and on the processes of verification of digital maps directly within the combat zone [10];

- the risks of deliberate distortion of topographic data by the aggressor as part of information and psychological operations aimed at misleading border guard units;

- the issue of cyber resilience of specialized geographic information systems used by border units under conditions of large-scale attacks on the critical digital infrastructure of the defense sector.

The necessity of resolving these contradictions under conditions of hybrid aggression determines the relevance of this study and defines its scientific direction. In an environment where the adversary

employs asymmetric methods of influence, geospatial data become not merely a background for conducting operations but a critical resource upon which the viability of the entire state border protection system depends [1]. Thus, despite the existence of general research developments in the field of defense, the issue of the specific impact of hybrid threats on the resilience and adaptability of geospatial support for border guard units remains insufficiently addressed in domestic military science. There is an urgent need for scientific substantiation of the transition from the concept of a "passive map" as a static representation of terrain to a strategy of "active geoinformation defense", where military topography functions as an integrated element of situational awareness [3].

The above determines the choice of the research topic and defines its objective, which is to develop the conceptual foundations of resilient geospatial support for the State Border Guard Service of Ukraine as an active and high-tech instrument for countering hybrid influences at the state border. This involves not only a reassessment of the role of military topography within the system of support to forces, but also the development of new algorithms for the verification and protection of spatial data in a dynamic security environment [9].

The purpose of the article is to conduct a comprehensive scientific study and to provide a theoretical substantiation of the strategic role of geospatial support in ensuring the resilience of the state border protection system of Ukraine, as well as to identify ways of adapting this system to the challenges posed by modern hybrid threats.

Achieving this objective requires a revision of outdated approaches to topogeodetic support in favor of a dynamic model capable of functioning under conditions of high information uncertainty and continuous terrain transformation. The study is based on the scientific idea of transforming military topography from a passive informational resource into an active, integrated component of the system of fire and maneuver control of border guard units. The research is grounded in the hypothesis that the implementation of intelligent geographic information systems and the transition to the concept of a "digital border" will make it possible to mitigate the adversary's advantages in hybrid warfare. This is achieved through the creation of a unified, reliable geospatial environment characterized by a high level of resilience to the effects of electronic warfare systems and hostile cyber interference with critical digital infrastructure.

To achieve the stated objective, the following main tasks have been defined:

1) to analyze the specific impact of modern hybrid threats, in particular electronic warfare (EW)-induced disorientation and deliberate manipulation of spatial data, on the functioning of the geospatial support system of the State Border Guard Service of Ukraine, and to assess the risks of an "information vacuum" emerging during combat engagements;

2) to substantiate a conceptual model of a resilient geospatial data system that integrates NATO standards (in particular, the GEOINT doctrine), Earth observation data, and autonomous navigation methods to ensure continuous situational awareness of border guard units;

3) to develop practical recommendations for the modernization of technical and software capabilities of the State Border Guard Service of Ukraine in the context of creating a unified geoinformation space for national security and defense.

Summary of the main material. The ongoing transformation of Ukraine's national security architecture, driven by large-scale armed aggression and the rapid evolution of asymmetric warfare methods, objectively requires a conceptual reassessment of the role and place of geospatial support within the overall system of state border protection and defense [1]. Under conditions of hybrid confrontation, where the boundary between peacetime law enforcement activities and active combat operations during wartime is often blurred, and where kinetic strikes are combined with information and psychological operations as well as cyber interference, geospatial support ceases to be merely a technical service function limited to the provision of paper-based or static electronic maps. Instead, it is evolving into a system-forming element that ensures the functioning of agencies and units within the security and defense sector, which is consistent with current doctrinal and regulatory documents in the field of topogeodetic and cartographic support [9].

At the present stage, geospatial support is transforming into a dynamic, high-tech, and intelligent system of situational awareness that provides a reliable spatial foundation for real-time strategic and tactical decision-making [7].

The results of the study suggest that the overall resilience of the state border protection system directly correlates with the level of autonomy, timeliness, and security of the geospatial environment against external disruptive influences, including informational and electronic warfare

effects [4]. In this context, military topography is considered as a functional component of geospatial support integrated into a unified geoinformation environment, which ensures spatial coherence of command and control and enhances the resilience of the border protection system under hybrid threats.

A key aspect of this transformation is the transition to a network-centric command and control model, within which geospatial data serve as an integrating foundation for intelligence, surveillance, command, and fire support systems. Within this approach, geospatial support ensures not only terrain orientation but also the formation of a unified and reliable spatial framework for synchronized interaction between border patrols, units of the State Border Guard Service of Ukraine, artillery assets, and air support [6]. The availability of a common geospatial operating environment makes it possible to minimize delays in the transmission of coordinates, improve the accuracy of targeting, and ensure interoperability of actions within a unified operational space.

Under conditions of hybrid confrontation, particular importance is attached to the ability of the geospatial support system to maintain continuity of operations and to recover under conditions of active employment of electronic warfare by the adversary, aimed at suppressing or distorting signals of global navigation satellite systems (GNSS). This necessitates the implementation of autonomous navigation methods in the activities of the State Border Guard Service of Ukraine, as well as the оперативного update of geospatial data through the use of unmanned aerial systems, which makes it possible to prevent the emergence of an "information vacuum" and to preserve command and control of units during the most critical phases of combat engagements [10]. In this way, geospatial support acquires the characteristics of an active deterrence instrument, transforming complex physical and geographical terrain conditions into a factor of strategic advantage for the defenders of the state border.

At the same time, under conditions of transformation of the state border protection system, the issue of convergence between geospatial support technologies and the level of professional training of personnel of the State Border Guard Service of Ukraine becomes critically important. The improvement of professional training of border guards within the framework of geospatial support, particularly in the use of mobile geographic information systems and

navigation tools under conditions of active electronic warfare, is reasonably considered one of the strategic priorities of institutional development. It is precisely the combination of technological capabilities and the cognitive competencies of personnel that determines the effectiveness of the use of geospatial data in real operational and service activities.

The resilience of the state border protection system under conditions of non-conventional conflict directly depends on the ability of each officer and non-commissioned officer to promptly verify geospatial information and integrate it into the unified information environment of the security and defense sector. Such an approach makes it possible to significantly reduce the vulnerability of units to hybrid influences and to ensure the inviolability of the state border through the formation of an intellectual and technological barrier. In this context, military topography performs the function of an integrating component of geospatial support, ensuring the unity of spatial perception, the reliability of navigation solutions, and the resilience of command and control under conditions of informational and electronic warfare counteraction.

A fundamental issue requiring scientific consideration in the context of ensuring the resilience of the state border is the phenomenon of geospatial and navigational disorientation, which under modern conditions is reasonably regarded as one of the key hybrid threats. The implementation of this threat is carried out through the large-scale use by the adversary of electronic warfare capabilities and navigation spoofing technologies aimed at distorting or imitating signals of global navigation satellite systems, which directly undermines the resilience of the state border protection system [1, 7]. It has been established that the formation of so-called "information vacuum" zones in border areas is aimed at paralyzing command and control systems, distorting targeting processes, and creating favorable conditions for the covert infiltration of sabotage and reconnaissance groups. Under such conditions, the transformation of approaches to terrain analysis objectively requires the implementation of comprehensive geoinformation technologies into the national security system, which makes it possible to minimize the impact of navigational and geospatial threats and to enhance the resilience of command and control of units [5, 9].

The scientific idea of the study is to develop the concept of "cognitive geospatial resilience", which is based on the implementation of a multi-level navigation redundancy system. Within this

concept, modern geoinformation platforms and digital cartographic data compatible with NATO standards are integrated with autonomous inertial navigation systems, which is consistent with contemporary doctrinal approaches to geospatial support of forces [6, 7]. Even under conditions of active use of intelligent solutions, including "digital twin" technologies of the terrain, the human factor remains a key element of geospatial support. Officers, possessing an adequate level of professional training in military topography as a component of geospatial support, perform the role of an intellectual verification filter, enabling the correlation of digital data with the real physical and geographical characteristics of the terrain, their оперативне updating through the use of unmanned aerial systems, and the detection of signs of camouflage or artificial transformation of landmarks by the adversary within a unified system of topogeodetic and cartographic support [3, 8, 10].

The methodological foundation of the proposed concept of "cognitive geospatial resilience" objectively necessitates a revision of didactic approaches within the system of professional training of personnel of the State Border Guard Service of Ukraine [4]. Within this approach, the implementation of "hybrid navigation" algorithms is proposed, which presuppose the ability of border guard units to operate effectively under conditions of full or partial degradation of GNSS signals. The implementation of such algorithms is achieved through the targeted development of visual navigation skills based on natural and artificial terrain features [3], combined with the use of offline cached cartographic databases and geoinformation technologies [5]. This synergy transforms a specialist from a passive operator of technical systems into a geospatial information analyst capable of identifying navigational anomalies, critically assessing the reliability of digital data, and making well-grounded decisions under conditions of deliberate information and technical influence by the adversary [1].

The practical implementation of the research results involves the establishment of specialized "geospatial stress-testing" training ranges, where scenarios of active electronic warfare suppression and navigation spoofing are simulated. Within such training activities, personnel practice methods of coordinate verification through triangulation based on distinctive terrain features, as well as the use of autonomous inertial sensors [8]. The author of study [1] emphasizes that only through the development of such comprehensive resilience – technical, informational, and cognitive – can the

state border protection system effectively counter the asymmetric methods employed by the adversary. This ensures not only physical control over the territory but also dominance in the information and geospatial domain, which is critically important for maintaining sovereignty in accordance with modern doctrines of geospatial support [7]. An important scientific and practical result of the study is the substantiation of the need to transition from static cartographic models to the concept of a "digital twin of the state border" (Digital Twin), which corresponds to leading global trends in the development of geospatial systems [8]. This integrated environment combines high-precision digital terrain models with dynamic layers of spatial data updated through Earth observation technologies and unmanned aerial systems [10]. The use of synthetic aperture radar (SAR) imagery, which enables monitoring through cloud cover and during nighttime, allows the State Border Guard Service of Ukraine to maintain border "transparency" under all conditions, which is a priority within the framework of institutional transformation [2, 4]. The author's contribution in this area lies in the development of algorithms for automated predictive terrain analysis. The necessity of applying such approaches is consistent with contemporary doctrinal provisions for the development of geospatial support, including NATO standards and regulatory documents of the security and defense sector of Ukraine [7, 9]. In particular, the application of mathematical modeling methods such as "Least Cost Path" makes it possible to determine the most probable routes of adversary movement, taking into account slope steepness, vegetation characteristics, and seasonal soil passability [3]. Such an approach transforms the classical functions of military topography into a predictive tool within a unified GIS platform [5]. This enables commanders to conduct proactive maneuvering of reserves and to optimize the density of deployment of fire support assets, thereby ensuring a technological advantage under conditions of hybrid aggression [1, 6]. The integration of a "digital twin" into the unified information environment of the security and defense sector creates the preconditions for the implementation of a network-centric border protection concept [8]. Through the real-time streaming of geospatial metadata from unmanned aerial systems directly into automated command and control systems, the time from detecting changes in the geospatial and technical state of the terrain (for example, the construction of crossings or engineering obstacles by the adversary) to

decision-making on fire engagement is reduced to a minimum [10]. This enables the mitigation of the adversary's advantage in manpower through technological superiority and precise orientation in a dynamic combat environment. Thus, the digital model evolves from a mere map into an interactive framework for the coordination of all forces and assets involved in the defense of the state border within a unified geospatial support system [9]. The final stage of implementing the research results should involve the incorporation of the developed algorithms into departmental regulatory and legal acts, as well as operational doctrines of the State Border Guard Service of Ukraine [2]. The author of study [6] emphasizes the importance of standardizing formats for the exchange of geospatial data with NATO partners, which will ensure full operational interoperability during joint operations. The scientifically substantiated transition from passive observation to active digital modeling of space is a key factor in transforming the border agency into a model of a modern high-tech institution [4]. The implementation of these approaches not only strengthens the defense potential of the state but also creates a reliable shield against various forms of hybrid expansion in the geospatial domain [1, 5]. Particular scientific attention should be given to the integration of the Ukrainian segment of border management into the unified security space of NATO member states. It has been established that the full implementation of NATO standards (in particular in the field of geospatial support and digital mapping) and the transition to the unified global geodetic coordinate system WGS-84 are not merely technical prerequisites but strategic factors for the survivability of units on the battlefield. The unification of classifiers and conventional symbols, as provided for in modern doctrinal documents, transforms geospatial data into a "universal language" of interagency interaction. This enables units of the State Border Guard Service of Ukraine to operate as active elements of a unified fire control network, providing accurate target designation for artillery and aviation without delays associated with coordinate conversion or terminology alignment. Such network-centric use of data within geospatial support ensures a qualitative advantage over the adversary in terms of decision-making speed, in line with the OODA loop concept. The human factor within this system, supported by fundamental knowledge of military topography, serves as a guarantor of information verification under conditions of electronic warfare counteraction. At the same time, the process of

transition to NATO standards should not be limited solely to the instrumental component. An important aspect is the development of a unified methodology for terrain analysis in accordance with Alliance standards (in particular, through the use of analytical frameworks such as OCOKA/KOCCOA), which enables border guard units to rapidly integrate into joint operational plans. This creates the conditions for the formation of a so-called Common Operational Picture (COP). The implementation of this technology enables the synchronization of actions of the State Border Guard Service of Ukraine units with other components of the Defense Forces of Ukraine and international partners, ensuring a shared and consistent understanding of the geospatial environment at all levels of command – from the tactical level to the strategic headquarters.

Furthermore, the scientifically substantiated integration of data into a unified security environment requires the establishment of a secure infrastructure for the exchange of geospatial intelligence (GEOINT). This involves not only the use of interoperable data transmission protocols but also the implementation of cloud-based solutions for the storage and processing of large volumes of digital cartographic data. Such an approach makes the border protection system resilient to the physical destruction of local communication nodes or documentation archives. Therefore, strategic advantage under conditions of hybrid confrontation is achieved through the development of a flexible, adaptive, and fully interoperable geospatial support system capable of self-recovery and scalability during critical phases of the conflict. Within the framework of the study, the authors propose a radical transformation of the architecture of geospatial support for national security. Given the high vulnerability of centralized databases to cyberattacks and the physical destruction of server infrastructure, they substantiate the feasibility of developing a decentralized cloud-based system for storing spatial information with local replication at the level of border guard detachments. This ensures that even in the event of a complete disruption of external communication channels or large-scale attacks on national backbone networks, each border protection unit retains access to up-to-date offline maps of its area of responsibility. Such technological independence from foreign commercial services is critically important for preventing the leakage of information regarding border engineering infrastructure and the deployment of forces, which aligns with the

priorities of the transformation of the State Border Guard Service of Ukraine.

The development of such an autonomous infrastructure requires the implementation of specialized national encryption protocols for geospatial metadata that comply with the requirements for the protection of state secrets and the standards of topogeodetic support of the Defense Forces. The authors propose the creation of a multi-level access system in which each level of map detail (from overview to operational-tactical) is dynamically adapted to the authorization level of a specific user. This makes it possible to mitigate the risks of "cascading" information leakage: even in the event of the loss of an end-user device, the decentralized architecture prevents access to the global data set, isolating only the local segment. Thus, "geospatial resilience" becomes an integral component of the overall cybersecurity of the border agency and a foundational element in the training of future officers. An important direction in the development of a decentralized system is the integration of machine learning algorithms directly on end-user devices (Edge AI), which is consistent with modern approaches to spatial data processing [8]. This enables units of the State Border Guard Service of Ukraine to conduct primary analysis of aerial imagery and radar data without the need to transmit large volumes of traffic to central servers, which is critically important for maintaining system resilience under conditions of hybrid threats [1]. Automated detection of changes in the terrain (such as the emergence of new tracks, clearings, or camouflaged objects) is carried out autonomously within the local cloud of a border guard detachment using unmanned aerial systems, allowing for the prompt updating of geospatial data [10]. Such an approach not only conserves the limited capacity of communication channels under conditions of active adversary electronic warfare, but also ensures an unprecedented speed of response to attempts to violate the inviolability of the state border, transforming classical topographic training into high-tech geospatial support [4, 9]. The use of such intelligent GIS technologies constitutes a foundation of the modern national security and defense system [5]. In conclusion, it should be emphasized that the transition to a decentralized architecture of geospatial support is a key step toward the creation of an "intelligent border" [4]. The author of study [1] substantiates that the combination of local autonomy with global cloud synchronization creates the effect of a "living organism" capable of rapid adaptation and

recovery from any external disruptive influences. This establishes the foundation for the development of a new strategy of geospatial support, in which technological independence and AI-driven automation algorithms serve as guarantees of the stability of the entire national security system of Ukraine in the long term [2, 9]. The further development of geospatial support is associated with the large-scale implementation of AI-based computer vision algorithms for the full automation of landscape change detection and interpretation [5, 8]. Under conditions of intensive combat operations, terrain and landscape structures change at an extremely rapid pace: artillery craters, destroyed bridges, and the construction of new fortifications by the adversary create a new physical reality. The author's concept of "dynamic mapping" involves the continuous comparison of current UAV imagery with reference digital terrain models, implemented through specialized neural network-based AI algorithms [10]. This makes it possible to automatically detect and signal the emergence of new objects within the security zone, significantly enhancing reconnaissance capabilities and minimizing the influence of the human factor within the overall geospatial support system in accordance with NATO standards [6, 7]. A significant advantage of implementing computer vision tools within the geospatial support system is the ability to identify concealed threats that remain invisible to the naked eye or to traditional observation methods. Under conditions of modern hybrid warfare, the application of multispectral and hyperspectral analysis, combined with artificial intelligence algorithms, is of particular importance for detecting areas of artificial camouflage of enemy equipment and personnel. Research findings indicate that the spectral signatures of live vegetation differ significantly from those of camouflage nets or cut branches, enabling automated systems to detect preparatory actions of the adversary at early stages, including during the formation of provocations [5, 8]. Under such conditions, dynamic mapping transforms into an element of predictive reconnaissance, where each pixel of geospatial data serves as a source of verified operational information integrated into a unified decision-support system. The automation of landscape change interpretation within geospatial support enables the implementation of the concept of the adversary's "digital footprint". AI-based systems accumulate and analyze the history of spatial changes in specific sections of the state border, identifying patterns in the preparation of engineering structures, logistical routes, and

positional deployment [6, 9]. This makes it possible not only to detect the emergence of new objects but also to predict the adversary's subsequent actions based on identified behavioral patterns, which is consistent with modern NATO approaches to geospatial intelligence and military engineering support [7]. Thus, geospatial support acquires the characteristics of an active instrument of intellectual confrontation, providing the command of the State Border Guard Service of Ukraine with objective data for strategic planning and the rational allocation of resources in the most vulnerable sectors of border protection [4].

The integration of artificial intelligence into the geospatial support system lays the foundation for the development of modern Decision Support Systems oriented toward anticipatory threat response. Under conditions of hybrid warfare, advantage is achieved not only through firepower but primarily through the speed of intellectual processing of geospatial data and its analytical interpretation [1]. The development of national AI algorithms adapted to the physical and geographical characteristics of Ukraine's landscapes is considered a key prerequisite for the implementation of the "Smart Border" concept, which ensures the inviolability of the state border through the creation of a high-tech intelligent filtering system [2, 5].

Particular attention in the study is given to the physical-geographical and environmental factors influencing the resilience of the state border protection system. Geospatial support should integrate data from hydrological and hydrometeorological monitoring of border rivers and wetland areas, as these natural features may be exploited by the adversary as instruments of hybrid pressure [3]. Modeling potential flood zones resulting from the destruction of hydraulic structures, as well as assessing the passability of marshy terrain during seasonal thaw periods, is critically important for planning engineering defense and maneuvering of forces [7].

The integration of soil science and hydrometeorological data into geospatial support enables the development of dynamic maps of terrain "tactical capacity". Seasonal fluctuations in groundwater levels and soil bearing capacity directly affect the feasibility of deploying heavy equipment and air defense assets along the border [3]. The use of predictive soil trafficability models allows the command of the State Border Guard Service of Ukraine to identify in advance periods of increased vulnerability of specific sectors, when natural barrier properties are temporarily

diminished [10]. In this way, geospatial support is transformed into an instrument of strategic deterrence, reducing the element of surprise in the adversary's actions. A distinct area of focus is the provision of environmental security of border territories as an object of hybrid influence. The use of multispectral imaging enables the detection of deliberate damage to ecosystems – including artificial fires and contamination of water bodies – which may be employed to conceal adversary movements or to divert the forces of the State Border Guard Service of Ukraine [5]. Geospatial monitoring of vegetation cover and thermal anomalies ensures the timely identification of such threats and enhances the effectiveness of response measures [8]. The final component of ensuring the resilience of the state border protection system is the transformation of the training system for officer personnel of the State Border Guard Service of Ukraine. Modern geospatial support requires the training of a new type of specialist – geospatial analysts capable of operating effectively both in conditions of digitalization and under technological constraints [4]. The introduction of training complexes based on virtual and augmented reality technologies into the educational process enables the simulation of complex border protection scenarios, taking into account terrain features, electronic warfare effects, and navigation disruptions, which corresponds to modern NATO training standards [7].

Conclusions

As a result of the comprehensive study, it has been established that under conditions of modern armed aggression and hybrid challenges, geospatial support is transforming from a specialized type of support into a strategic instrument for strengthening national security resilience. The scientific novelty of the obtained results lies in rethinking the role of topogeodetic and cartographic support as a dynamic system of situational awareness capable of functioning effectively under conditions of active electronic warfare and information confrontation. An important scientific result is the theoretical substantiation of the concept of navigation multimodality, in which autonomous inertial systems are integrated with the cognitive skills of spatial verification of personnel in order to mitigate the risks of navigation denial. This makes it possible to create a multi-level redundancy system in which the human factor, supported by

fundamental training in military topography, serves as a guarantor of the reliability of digital data. The development of a digital twin model of a border section enables predictive threat analysis through the synthesis of static topographic foundations with dynamic data from unmanned aerial systems and Earth observation technologies. The implementation of this technology based on NATO standards ensures full operational interoperability of the State Border Guard Service of Ukraine with other components of the Defense Forces, enabling accurate interagency fire support. At the same time, the necessity of transitioning to a secure decentralized cloud-based architecture for departmental spatial data has been substantiated, which is critically important for the survivability of command and control systems under conditions of large-scale cyberattacks. The improvement of methodological approaches to personnel training through the implementation of modern geoinformation technologies contributes to the development of stable spatial thinking among future officers, which is necessary for identifying topographic disinformation.

Prospects for further research are associated with the development of automated methods for the intelligent analysis of spatial data aimed at detecting concealed changes in terrain and enemy engineering infrastructure in real time.

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**РОЛЬ ТА МІСЦЕ ГЕОПРОСТОРОВОЇ ПІДТРИМКИ У ЗАБЕЗПЕЧЕННІ
СТІЙКОСТІ СИСТЕМИ ОХОРОНИ ДЕРЖАВНОГО КОРДОНУ
В УМОВАХ ГІБРИДНИХ ЗАГРОЗ**

Подано комплексне теоретичне обґрунтування ролі і визначено стратегічне місце геопросторової підтримки в загальній структурі системи охорони державного кордону України. В умовах сучасних гібридних загроз автори наголошують на критичній зміні парадигми: функції військової топографії сьогодні інтегровані в системне поняття «геопросторова підтримка», що охоплює топографію, геодезію, картографію та навігацію. Доведено, що стійкість системи охорони кордону безпосередньо залежить від точності просторових даних, що інтегровані з новітніми геоінформаційними технологіями.

Розкрито специфіку гібридних загроз, за яких противник застосовує засоби радіоелектронної боротьби та навігаційний спуфінг, що вимагає від підрозділів Державної прикордонної служби України високого рівня ситуаційної обізнаності та здатності до когнітивної верифікації місцевості. Значну увагу приділено цифровізації та впровадженню концепції «цифрового двійника» кордону, що дає змогу моделювати оперативну обстановку в режимі реального часу за допомогою безпілотних авіаційних комплексів та автоматизованих методів аналізу.

Наголошено, що інтеграція сучасної геопросторової підтримки в систему національної безпеки є стратегічною вимогою, яка дає можливість мінімізувати ризики неконвенційних конфліктів. Наукова новизна праці полягає в уточненні функціональних завдань системи підтримки військ відповідно до сучасних доктрин та стандартів НАТО. Практична цінність результатів дослідження полягає у можливості їхнього впровадження у нормативно-правову базу та методичку підготовки офіцерських кадрів Державної прикордонної служби України.

***Ключові слова:** Державна прикордонна служба України, національна безпека, гібридні загрози, геопросторова підтримка, геоінформаційні системи, ситуаційна обізнаність, цифрова картографія.*

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