

ABSTRACT

**of the doctoral dissertation for the degree of Doctor of Philosophy
(PhD) in the specialty "6D071100 – Geodesy"**

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Topic: «Geodesic methods for studying the state of natural and man-made objects using satellite technology»

Relevance of Research. In the context of intensive subsurface development, large-scale infrastructure growth, and the high risk of anthropogenic and natural disasters in the Republic of Kazakhstan, continuous and high-precision monitoring of natural and technical objects is becoming critically important.

The relevance of the research is due to the need to switch to integrated satellite technologies for the rapid detection and forecasting of Earth surface movements, deformations of large industrial complexes, mining facilities and infrastructure networks, which correspond to the Sustainable Development Goals (SDGs) No. 9 «Industry, Innovation, and Infrastructure». Improving methods for collecting and processing geospatial data based on satellite technologies is a key factor for minimizing risks, improving industrial and environmental safety, and ensuring sustainable regional development, which directly corresponds to SDG No. 11 «Make cities and human settlements inclusive, safe, resilient and sustainable».

The subject of this study corresponds to the priority directions of the development of science in the Republic of Kazakhstan in the field of rational use of mineral resources and safety of industrial facilities. The work meets the requirements of modern digitalization of the mining industry within the framework of the "Industry 4.0" concept, which involves the transition to high-tech methods of digital data collection and processing.

The Objective of the Work is to develop the scientific and methodological foundations and an integrated geodetic technology for monitoring the state of natural and technogenic objects in the Republic of Kazakhstan using satellite data to improve the accuracy and speed of deformation detection and forecasting, thereby ensuring the geodynamic safety of regions.

The Main Idea of the Work of the work lies in developing a methodology for the comprehensive monitoring of natural and technogenic objects based on modern digital geodetic surveying methods and satellite technologies.

Research Tasks:

– Perform a critical theoretical analysis and systematization of global experience in applying integrated satellite technologies (GNSS, InSAR) for monitoring anthropogenic and natural deformations;

- Develop an integrated methodology for the collection, processing, and joint analysis of geospatial data from various satellite and terrestrial geodetic systems to ensure high accuracy and reliability in observing undermined land surfaces;
- Conduct pilot geodetic works on key natural (Baden-Württemberg district) and man-made objects (Karaganda coal basin area, Atasu iron ore deposit) to build spatial and temporal models of the earth's surface;
- Substantiate the application methodology and develop recommendations for planning aerial photogrammetric work using unmanned aerial vehicles to improve the productivity and accuracy of topographic surveys on a scale of 1:500-1:2000 with a relief section of 0.5 meters.

Research Methodology Includes:

- Analysis and synthesis of literature on modern geodetic instruments and surveying methods;
- Laboratory studies of the measurement error of the phase center of the antennas of global navigation satellite systems of the space and user segment;
- Pilot validation of research results in the Karaganda coal basin, the Atasu iron ore deposit, and forest/agricultural plots in the Baden-Württemberg region (Germany);
- Substantiation of recommendations for designing satellite geodetic networks for monitoring technogenic objects via Unmanned Aerial Vehicles (UAVs).

The Subject of Research includes the undermined land surfaces in the mining allotments of the Atasu iron ore deposit and the Karaganda coal basin, as well as agricultural fields and lands in the Baden-Württemberg region (Germany).

Research Methods include satellite radar interferometry, GNSS measurements, remote aerial photography, high-precision geometric leveling, mathematical processing and statistics, and programming in the Python environment.

Scientific Novelty of the Research lies in:

- Applying progressive technological solutions in geodesy based on InSAR and GNSS measurements combined with high-precision leveling to identify patterns in the mechanism of land surface deformation during mining operations and landscape changes in agricultural areas during the growing season.
- Determining displacement values in areas under stress-strain conditions using InSAR as the most informative measurement method for hazardous zones, allowing for the detection of subtle deformation processes.

The Scientific Significance of the work consists in forecasting the state of the land surface during underground mining by implementing digital measurement technologies and remote sensing to identify deformation mechanisms, landscape changes in crop fields over seasons, and improving measurement accuracy.

Scientific Provisions Submitted for Defense:

- The developed methodology for extracting vegetation parameters of natural objects with varying land cover types using Sentinel-1A data is based on establishing a correlation between calculated satellite indices and ground-based field observations, providing a reliable assessment of vegetation status.
- To develop an automated calculation and visualization of the parameters of the GNSS antenna phase center using mathematical calculations and diagramming in the Python software package based on absolute calibration data to ensure high internal accuracy of the GNSS component;
- To develop and implement an integrated geomechanical monitoring system at man-made mining facilities, including satellite remote sensing, GNSS measurements, high-precision digital leveling and aerial photogrammetry from UAVs.

The reliability and validity of the research results is due to a significant review of literary sources, conducting field measurements directly on objects, processing high-resolution satellite radar data, which are based on major achievements in the field of geodesy, remote sensing of the Earth and geomechanics by substantiating man-made processes of displacement of the Earth's surface of the mined territories, comparing the results of space radar interferometry, high-precision digital leveling, aerial photography from UAVs, and the compliance of the data obtained with the current regulatory documents.

The theoretical significance of the work lies in:

- an integrated approach to the study of the processes of deformation of the earth's surface in the mined areas, based on the identification of patterns of surface changes depending on the degree of mining of the mountain range, which allows for more accurate prediction of deformations and prevent negative consequences for the environment and infrastructure.
- determining the magnitude of displacements of the Earth's surface under stress conditions, which is achieved by using satellite radar interferometry, which makes it possible to obtain spatial and volumetric information about the process of deformation of the Earth's surface, including subtle changes. The advantage of interferometry lies in its high accuracy and the ability to measure in hazardous areas where other methods may be difficult.

- the use of high-precision geometric leveling using digital laser devices, which makes it possible to detect the displacement of the Earth's surface in the affected areas at an early stage and respond in a timely manner to changes and prevent emergencies.

- the well-founded application of the aerial photogrammetric method of surveying using unmanned aerial vehicles, which makes it possible to create digital terrain models for planning and safely carrying out remediation works in order to improve risk management.

Practical Value and Implementation

Practical Value: Within the integrated approach developed for monitoring critical objects in the Karaganda coal basin and Atasu deposit, the InSAR method is used for the primary detection and localization of active deformation zones. Following the identification of subsidence troughs, the aerophotogrammetric method using the DJI Mavic 2 Pro UAV is applied for rigid calibration and detailed validation of DInSAR results. The survey control for aerial photography is established using Leica GS14 high-precision GNSS receivers. Ground control points (GCPs) in the form of contrast circles are used for georeferencing and minimizing residual errors, ensuring the accuracy required for topographic surveys at scales of 1:500–1:2000.

Implementation of Results. The obtained research results were implemented in the mines of the Karaganda coal basin, implemented in the activities of the Orken-Atasu Representative Office of Orken LLP, certain provisions of the dissertation work were used in monitoring agricultural sites in Baden-Württemberg (Germany), as well as the developed observation methodology are used in the educational process of the Department of Surveying and Geodesy of the NAO Karaganda Technical University. Abylkas Saginov University" when giving lectures and conducting student scientific research.

The dissertation was conducted within the framework of Commercial Contract No. 23.11.04, titled "Investigation of the day surface in the impact zone of blasting operations and control of the quarry reclamation process at the Representative Office of Orken-Atasu LLP." The proposed research methods were used in the implementation of scientific projects AP09058619, 0213RK01341, which is confirmed by the list of publications. The research was carried out as part of a scientific and technical collaboration with the German Academic Exchange Service (DAAD) under project No. 57558719, "Cooperation in the Interdisciplinary Environment of Construction and Geodesy," at the Berlin University of Applied Sciences (BHT) in Germany, under the supervision of a foreign scientific consultant.

Furthermore, this work was executed within the international research project GEO3889, supported by the German Aerospace Center (DLR),

specifically regarding access to an archival dataset of TerraSAR-X satellite radar imagery (126 scenes).

Personal Contribution of the Author consists in formulating the research problem and objectives, developing methodologies and models, and conducting analytical, experimental, and field observations.

Publications and Approbation:

Three articles have been published on the topic of the dissertation in rating journals included in the Scopus database and the Web of Science "InSAR-Based Assessment of Land Subsidence Induced by Coal Mining in Karaganda, Kazakhstan" journal "Geomatics", publishing house Multidisciplinary Digital Publishing Institute (MDPI), Q2, Switzerland; "Analysis of Undefined Ground Surface Movements at the Atasu Iron Ore Deposit", Journal of Mining Science, Springer Publishing House, Q3, USA; "The research study in the convergence of the results of processing radar images Sentinel-1A with field observations of agricultural sites" Geodesy and Cartography journal, Roskadastr Publishing House, Q3, Russian Federation; six articles in publications recommended by the Committee for Control in the Field of Education and the Ministry of Education and Science of the Republic of Kazakhstan; eight abstracts in collections of International conferences. Three utility model patents and three certificates of entry of information in the State Register protected by copyright have been obtained.

Patents on the entry of Sweden into the State Register of polesie models, published by the author's law:

- Patent No. 7006 for the field model "Pylon Geodetic connection" Registration Number application 2022/0073.2 from 03.02.2022;
- Patent No. 8814 for the field model "Construction of leveling shoes" Registration Number application 2023/1129.2 from 15.11.2023;
- Patent No. 37751 for the invention of the "Universal Geodetic pylon" from 16.01.2026.

Ministry of state registration of rights to objects of the author's right:

- No. 33846 "analysis, protection and planning of forest resources using UAVs", date of registration 27.03.2023;
- No. 41902 "monitoring the Earth's fertility in the region of the city of Karaganda", Registration date 10.01.2024;
- No. 59974" creation of topographic plans with the help of UAVs (UAVs)", date registration 19.06.2025.

Structure and Volume of the Work: The dissertation consists of an introduction, 4 sections, a conclusion, a list of references, and appendices. The volume is 134 pages, containing 17 tables and 87 figures.