ABSTRACT

For the dissertation submitted for the degree of Doctor of Philosophy (PhD) in specialty 6D071100 – Geodesy

Yerzhankyzy Ainur

DEVELOPMENT OF METHODOLOGY AND TECHNOLOGY FOR CREATING DIGITAL TERRAIN MODELS (DTM) IN ROAD DESIGN AND RECONSTRUCTION

A distinctive feature of digital terrain models (DTMs) for road design and reconstruction is their high accuracy and detail, which is essential for enabling the automation of construction machinery on-site and for the prompt execution of geodetic as-built control of the completed work results.

Relevance of the Topic. Recent decades have been marked by the intensive implementation of high-tech tools and equipment in the processes of road construction and reconstruction. The impact of these technologies is especially evident in the construction of modern high-speed highways and global transportation corridors, some of which pass through the territory of the Republic of Kazakhstan. The application of modern digital design methods and road construction technologies has become impossible without the introduction and comprehensive use of innovative geospatial methods and technologies, which serve as the foundation for all subsequent stages of construction.

The geospatial basis for road design and reconstruction is the digital terrain model (DTM). The creation of digital terrain models is carried out using advanced methods and technologies for collecting geospatial data, including geodetic methods that encompass various types of topographic surveying using electronic total stations and global navigation satellite systems (GNSS), photogrammetric methods for terrestrial and aerial imaging, airborne and terrestrial laser scanning techniques, as well as cartographic methods that utilize archival mapping data when available.

The problem of creating digital terrain models (DTMs) has been addressed in the works of scientists such as Hofmann H. and Young Hu. The task of data collection and analysis, as a basis for creating DTMs, is reflected in the works of Schults R.V. and Seredovich V.A. Existing methods and technologies for creating digital terrain models have been developed primarily to solve topographic and cartographic problems and are designed to meet the requirements for creating and updating topographic maps. These requirements, in turn, are regulated by standards for creating and updating topographic maps and plans, such as terrain representation accuracy, which must typically fall within one-third to one-fourth of the contour interval. This standard, even for flat terrain, does not exceed 7.5 cm, which falls short of construction norms, which often

demand higher accuracy and detail (up to 10 cm for design and up to 5 mm for reconstruction).

On the other hand, widely used modern technologies like terrestrial laser scanning, aerial imaging with unmanned aerial vehicles (UAVs), and airborne laser scanning can meet these higher requirements. However, these technologies are not yet adequately represented in construction regulatory documents, which lack established standards, criteria, and recommendations for their application. As a result, the adoption of these technologies in the execution of high-precision construction work is hampered by the absence of harmonized regulatory requirements. These requirements, in turn, must be supported by a developed methodology and technology for creating DTMs to meet the needs of road design and reconstruction.

Thus, achieving the goal of this dissertation involves researching modern methods and technologies for collecting geospatial data for creating DTMs, as well as improving existing mathematical models for constructing DTMs. Together, this represents a significant scientific and practical task, the solution of which is of both scientific and high practical value.

Research Goal – The development of a methodology and the improvement of technologies for creating digital terrain models (DTMs) to address the challenges of road design and reconstruction.

Research Object – Digital terrain models of roadways in the city of Almaty.

Research Subject – Methods and models for creating DTMs for road design and reconstruction.

In accordance with the dissertation topic, the following research tasks have been set and accomplished in this study.

1. Development of technological schemes for data collection and geodetic support for creating digital terrain models in the design and reconstruction of roads, using aerial imaging with unmanned aerial vehicles (UAVs) and terrestrial laser scanning.

2. Investigation of the accuracy of initial geospatial data acquisition for creating digital terrain models through UAV aerial imaging and terrestrial laser scanning methods.

3. Improvement of the methodology for selecting the appropriate method for constructing digital terrain models.

Research methods allow to achieve the goal set in the thesis work and reveal the essence and content of the obtained scientific results. The integrated method of research was used, which includes: analysis of literature sources on the application of aerial survey technology and terrestrial laser scanning; modeling of different terrain relief; data interpolation and construction of digital terrain models.

Scientific Propositions Presented for Defense:

1. The technological scheme for data collection and geodetic support, based on the integration of unmanned aerial vehicle (UAV) aerial imaging and laser scanning, involves combining these two methods to achieve maximum accuracy and detail in geospatial data, depending on the terrain characteristics.

2. A methodology for assessing the accuracy of initial geospatial data for creating digital terrain models using UAV aerial imaging and terrestrial laser scanning methods.

3. A methodology for constructing digital terrain models that ensures the required accuracy, meeting the standards for road design and reconstruction.

Scientific Novelty:

1. The technology for data collection to create digital terrain models in road design and reconstruction has been improved through the use of UAV aerial imaging and terrestrial laser scanning.

2. A methodology has been developed for examining mathematical models of digital terrain model construction using mathematical modeling and for assessing the accuracy of initial geospatial data for creating digital terrain models.

3. The methodology for selecting an appropriate method for constructing digital terrain models has been improved.

Practical Significance lies in:

1. **Enhancing the Accuracy of Digital Terrain Models (DTMs):** The developed methodological approaches and algorithms improve the accuracy of DTMs, which is particularly important for the design and construction of infrastructure projects.

2. **Implementing New Data Processing Methods:** Processing data obtained from various flight altitudes ensures a more accurate and detailed representation of terrain. The proposed methodologies and recommendations help reduce the labor intensity and cost of creating DTMs by optimizing flight altitude and surveying technologies.

3. **Justification and Reliability of Scientific Propositions, Conclusions, and Recommendations:** The validity is confirmed by applying the theory of measurement errors to study the accuracy of various geospatial data collection methods, using statistical methods, including analytical modeling to explore mathematical models of DTM construction, and employing comparative analysis to identify the optimal method and technology for geodetic support in creating digital terrain models.

The Author's Personal Contribution includes conducting an analysis of existing studies and publications on methods for creating and evaluating digital terrain models (DTMs). Practical recommendations have been formulated for selecting optimal methods and flight altitudes for DTM creation, depending on the specifics of tasks and terrain conditions.

Conclusions and Summary: New methodological approaches to DTM creation have been developed, considering the specifics of various flight altitudes and data sources. Algorithms have been proposed to improve the accuracy and efficiency of data processing obtained through various surveying methods.

Recommendations have been developed for the office processing of data and integration of various information sources to enhance the accuracy and completeness of DTMs.

The data collection technology, based on UAV aerial imaging and terrestrial laser scanning, ensures high accuracy and detail in geospatial data by integrating aerial and ground-based data. This approach improves design quality, reduces data collection time by 20%, and minimizes errors during road infrastructure reconstruction and construction through optimal flight altitude selection, considering terrain and surveying methods.

Publications and Approval of the Work. Based on the dissertation materials, 9 printed works have been published, including: one article in an international peer-reviewed scientific journal with an impact factor, *Naukovyi Visnyk Natsionalnoho Himychoho Universytetu* (Scopus Q2); three articles in publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of Kazakhstan; and four articles in proceedings of international conferences, forums, and congresses.

The research results have been implemented in educational and production processes, confirmed by relevant Acts.

The work is conducted within the framework of the targeted financing program IRN project: BR21882179 "Development of Predictive and Exploration Solutions for Geological Mapping of Ore Deposits Using Terrestrial and Space-Based Methods." One of the directions within this project involves creating high-precision digital terrain models (DTMs) that not only depict topographic features but also reveal linear and structural elements essential for ore deposit formation. These models serve as a foundation for lineament analysis used to identify tectonic faults and structural lines indicative of potential ore deposits. The accuracy of the DTMs developed within the project significantly enhances the quality of prediction and analysis of ore deposits, contributing to more effective exploration of promising areas for geological surveying.

Structure and Volume of the Dissertation.

The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. The work is presented in 110 pages of typed text, containing 36 tables, 55 figures, and a bibliography of 120 references.