ABSTRACT

of the dissertation by Orman Indira

entitled “Development of algorithms and software for determining the electromagnetic parameters of inclusions in the underlying environment”, submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D06101 – Computer Science, Computer Engineering and Management

Relevance of the Study. The modern development of transport infrastructure requires the implementation of high-precision methods for the rapid diagnostics of the technical condition of objects. One of the key challenges in this field is the non-destructive testing of multilayer engineering structures and underlying soils. Among existing technologies, ground-penetrating radar (GPR) occupies a special place. Despite its widespread use, the process of extracting quantitative characteristics of the environment (dielectric permittivity and electrical conductivity) remains labor-intensive and often requires significant computational resources.

The development of direct numerical algorithms that eliminate complex multi-step residual minimization is an urgent scientific and technical task. This research is particularly relevant in the context of the objectives outlined by the Head of State in the Address dated September 8, 2025, “Kazakhstan in the Era of Artificial Intelligence: Digital Transformation.”

Purpose of the Study.

To develop algorithms and software for determining electromagnetic parameters (dielectric permittivity and electrical conductivity) of inclusions in the underlying environment based on ground-penetrating radar data, including source calibration, depth estimation, and the application of deep learning methods for monitoring subsurface conditions.

Objectives of the Study.

1. To analyze existing GPR algorithms and methods for determining electromagnetic parameters of the underlying environment.
2. To develop and implement methods for depth estimation based on experimental studies using the “Loza-V” GPR system, as well as methods for determining dielectric permittivity and conductivity based on engineering approaches.
3. To develop methodological approaches for primary processing of real GPR data and determine the calibration function describing the influence of moisture content on dielectric permittivity.
4. To develop a methodology for monitoring and diagnosing the structural condition of subsurface layers using deep learning methods for GPR data interpretation.
5. To develop a method for determining source parameters using optimization techniques.
6. To develop a method for solving the problem of determining dielectric permittivity and conductivity of inclusions in the underlying environment based on an analytical solution of the geoelectric equation in the frequency domain.

Research Methods.

Engineering methods based on physically justified formulas; mathematical modeling of the source function in tabular form; determination of electromagnetic properties of inclusions in the underlying environment using an analytical solution of the geoelectric problem in the frequency domain; application of optimization methods; and the use of deep learning techniques (including recurrent neural networks such as LSTM).

Scientific Novelty of the Study

1. Methods for determining depth based on experimental studies using the “Loza-V” GPR system have been developed, along with methods for determining dielectric permittivity and conductivity based on engineering approaches.

2. Methodological approaches for the interpretation and primary processing of real GPR data for practical application have been proposed.

3. A methodology for monitoring and diagnosing the structural condition of subsurface layers based on deep learning methods has been developed, improving the accuracy of detecting heterogeneities and reducing dependence on expert subjectivity.

4. A method for determining source parameters using optimization techniques in tabular form has been developed.

5. A method for determining dielectric permittivity and conductivity of inclusions in the underlying environment based on an analytical solution of the geoelectric equation in the frequency domain without iterative optimization has been developed.

Main Results Submitted for Defense

1. Methods for depth estimation and determination of dielectric permittivity and conductivity based on experimental GPR studies have been developed and implemented, improving interpretation accuracy.

2. Methodological approaches for interpretation and primary processing of real GPR data have been proposed, including calibration functions relating moisture content to dielectric permittivity.

3. A deep learning-based methodology for monitoring subsurface structural conditions has been developed, improving accuracy and reducing subjectivity.

4. A method for determining source parameters using optimization techniques has been developed, improving model-data consistency.

5. An analytical method for determining electromagnetic parameters in the frequency domain has been developed, enhancing the accuracy of geophysical parameter reconstruction.

Practical Significance of the Study.

The developed algorithms and software can be applied to monitoring subsurface layers of road structures, construction sites, and in archaeology. This is due to the fact that the physical condition of underlying layers (e.g., high moisture content) and the presence of voids significantly affect the condition of upper layers, potentially leading to their destruction.

Object of the Study - Processes of propagation and reflection of electromagnetic waves in subsurface heterogeneous media during GPR sounding.

Subject of the Study - Algorithms and mathematical models for processing and interpreting GPR data.

Personal Contribution of the Author.

The author formulated and formalized the research tasks, developed mathematical models, computational methods, algorithms, and software for determining electromagnetic parameters of inclusions. Scientific publications were prepared, results were presented at international conferences and seminars, and practical implementation in industry and education was ensured.

Approbation and Publications.

A total of 5 scientific papers have been published, including: 3 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; 2 papers in international

conference proceedings; 2 articles in journals indexed in the Scopus database. The results were presented at scientific seminars and conferences, including: “Theory and Numerical Methods for Solving Inverse and Ill-posed Problems” (Novosibirsk, 2023); “Determination of Calibration Function of Dielectric Permittivity Dependence on Moisture” (Novosibirsk, 2024).

Implementation and Structure of the Dissertation.

The algorithms and software developed in the dissertation have been successfully implemented in the educational process of the Non-Commercial Joint-Stock Company “D. Serikbayev East Kazakhstan Technical University”, as well as in the activities of the Republican State Enterprise on the Right of Economic Management “National Center for Quality of Road Assets”, which is confirmed by relevant implementation certificates.

The dissertation consists of an introduction, four chapters, a conclusion, a list of references and appendices. The author expresses sincere gratitude to the scientific advisor — Candidate of Technical Sciences, Associate Professor Kurmashev Ildar Gusmanovich, the second scientific advisor — Doctor of Physical and Mathematical Sciences, Professor Iskakov Kazizat Takuadinovich, and the foreign scientific advisor — Doctor of Physical and Mathematical Sciences, Professor Amir Mosavi Aliahsraf for their scientific guidance and support.