to whom it may concern

Institutional Identification No.: NIK, 132, 2026
Budapest, 20.01.2026

REVIEW OF A FOREIGN SCIENTIFIC CONSULTANT

On the dissertation research of Indira Malikovna Orman

"Development of Algorithms and Software for Determining the Electromagnetic Parameters of an Inclusion in the Environment" submitted for the degree of Doctor of Science (PhD) in the specialty

8D06101 – "Computer Science, Computer Engineering, and Control

The aim of the dissertation research is the development of algorithms based on optimal control methods and software for determining the following: the electromagnetic properties of the inclusion; the disturbance source in tabular form; the depth of the inclusion in the underlying medium; the dielectric permittivity; and the conductivity using a non-destructive method with the application of the ground-penetrating radar equipment "Loza-V."

Relevance of the Research Topic: Ground-penetrating radar (GPR) systems are used for non-destructive testing and diagnostics in the construction of various structures, road surfaces (including airfields), and in mineral exploration. The range of such applications is extensive and covers a wide spectrum of tasks in both the national economy and the defense industry. A GPR system is capable of emitting electromagnetic signals into the investigated medium, receiving and recording the reflected electromagnetic signals, and subsequently constructing a radargram based on these reflections. A radargram a time scan at the observation point. The main aim of these experimental studies is to interpret radargrams. The engineering and technical method of investigation consists of comparing the obtained radargrams with the standard types available in the database, as well as performing additional calculations based on the theory of wave propagation in a medium. There are several modifications of GPR devices produced by different countries, designed to solve a wide range of tasks. However, the accompanying manuals often lack detailed descriptions of radargram interpretation methods. This is since the results of such research have commercial applications. The quality of radargram interpretation depends on the completeness of the database of reflected signals from inhomogeneities and on the experience and skills of the geophysicist, which introduces a significant degree of subjectivity.

Alternative approach to radargram interpretation is mathematical and computer modeling of the process of electromagnetic wave propagation and reflection in a medium. A radargram provides information about the signal travel time to an inhomogeneity, but in practice, there is a need to determine the physical characteristics of the inhomogeneity itself – such as dielectric permittivity, magnetic permeability, and electrical conductivity. To determine these parameters, the theory of ill-posed and inverse problems has become widely applied, experiencing rapid development in the 20th century. The foundation of this theory originates from the pioneering works of Academician A.N. Tikhonov. For various classes of problems, the theory of ill-posed and inverse problems was further developed in the works of Academicians M.M. Lavrentiev, V.I. Ivanov, their followers. Theoretical aspects, such as the issues of uniqueness and stability within the framework of well-posedness for inverse problems of mathematical physics, are presented in the monograph by V.G. Romanov. The theoretical foundations and numerical methods for solving inverse problems in geo-electrics are thoroughly discussed in the monograph by V.G. Romanov, S.I. Kabanikhin, and A.L. Karchevsky. The application of optimization methods for solving coefficient inverse problems is presented in the monographs by S.I. Kabanikhin and K.T. Iskakov.

<u>Theoretical Significance:</u> The upper layer of the medium in which the object is located is heterogeneous, which creates difficulties for the ground-penetrating radar (GPR) when studying the continuous structure of the medium. The medium can be heterogeneous - such as concrete, soil, and so on. The reflected electromagnetic pulses are recorded, which may either amplify or attenuate as they interact with each other. As a result, it may become impossible to detect an object beneath the layers. This problem can be addressed by modeling GPR data at depth in the direction of the inhomogeneity. In subsurface georadar surveying, the propagation of electromagnetic waves is described by the system of Maxwell's equations. This constitutes a continuation problem of the electromagnetic field, which studies the location of the desired objects from surface-level measurements. In mathematical physics, this problem is not a simple one. The difficulty lies in the fact that the electromagnetic field in conductive media is complicated by the presence of attenuation. In the theory of inverse and ill-posed problems, it is necessary to determine the boundary condition at the depth of the investigated object. This allows one to determine the medium's response based on the data measured by the GPR at the Earth's surface. Furthermore, it is essential that the solution of the mathematical modeling problem coincides with experimental data. To solve the problem representing the process of electromagnetic wave propagation, it is necessary to have a source function in either analytical or tabular form. Typically, GPR systems provide only the medium's response, which from a mathematical point of view is the trace of the direct problem's solution at the measurement point. For the correct interpretation of GPR data, the results of mathematical modeling must correspond to the mathematical description of the source function emitted by the radar. Only under these conditions will the mathematical model align with the results of experimental studies, including the transformation of GPR data to the depth of the investigated object. In this case, the geophysical properties of the artificial object, including its depth of occurrence, will be determined.

<u>Practical Significance:</u> The development of algorithms and software for solving the problem of determining the electromagnetic characteristics of inclusions can be applied in monitoring road surfaces, construction sites, as well as in archaeological research. This is due to the fact that the physical condition of the underlying layers (such as high moisture content or the presence of voids) undoubtedly affects the condition of the upper layers, potentially leading to their degradation or destruction.

<u>Methodological Foundations and Research Methods:</u> The research is based on the application of engineering and technical methods grounded in physically justified formulas; mathematical modeling of the source function in tabular form; and the determination of the electromagnetic properties of inclusions in the underlying medium using methods from the theory of inverse problems.

<u>Scientific Novelty of the Research:</u> All ground-penetrating radars record the travel time of signals from reflection boundaries. To determine the characteristics of the medium, it is necessary to transform the travel-time function into a depth profile. This very function provides information about the properties of the medium as a function of depth. To solve such problems, methods from the theory of ill-posed and inverse problems are employed. For numerical implementation, optimization methods from control theory are used.

The following results have been obtained:

1. A series of algorithms have been developed to determine the electromagnetic properties of inclusions based on mathematical modeling of the electromagnetic wave propagation process, using methods from the theory of inverse and ill-posed problems, as well as neural network techniques.

2. As a non-destructive method, electrical prospecting techniques using ground-penetrating radar equipment have been applied.

3. Algorithms and methods for signal processing and noise reduction have been presented, since such methods are usually considered commercial secrets by manufacturers and are not available for direct analysis. These data are extremely important as additional information for solving inverse and ill-posed problems.

4. Software products have been developed based on the above algorithms.

5. Control theory: Optimization methods have been applied to solve inverse problems.

6. Experimental studies have been conducted on artificial targets under field conditions using a ground-penetrating radar.

7. Laboratory studies have been carried out to determine the influence of the medium's humidity coefficient on the dielectric constant.

As the foreign scientific consultant, I confirm that Indira Malikovna Orman's personal contribution to obtaining these results is significant, and the work has been performed with a high degree of independence.

Based on the results of the dissertation research, 12 scientific publications have been produced, including 2 articles in journals recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 2 papers in journals indexed in the international Scopus database, and 3 publications in international conference proceedings.

As a result of the research, a certificate of state registration of rights for an intellectual property object (computer software and mathematical modeling) has been obtained.

The dissertation work of PhD student Indira Malikovna Orman fully complies with the requirements for dissertations submitted for the PhD degree in the speciality 8D06101 - Informatics, Computer Engineering and Control.

Novelty

This study introduces a new way to monitor the structural health of pavements using deep learning. It applies the Long Short-Term Memory (LSTM) model to predict pavement condition and remaining service life. Unlike traditional inspection methods that are costly and disruptive, this approach is non-destructive and data-based. The model uses real field data from FWD and GPR tests, which makes it both practical and reliable. It also connects AI, sensors, and road data to create a smarter and more efficient pavement monitoring system.

Research Objectives

The main goal of the study is to build a model that can predict the structural condition of pavements. It focuses on estimating the Remaining Service Life (RSL) using factors such as asphalt surface temperature, asphalt concrete thickness, and base thickness. The research tests several models, including SGD, XGBoost, ANN, ANN-PSO, ANN-GWO, AdaBoost, and LSTM. It aims to find which one works best for this type of data. The study identifies the most accurate and stable method for predicting pavement performance.

Practical and Strategic Goals

The study also aims to help transportation agencies make better maintenance decisions. By using AI-based models, they can plan repairs earlier, save costs, and improve road safety. The system can link with smart city and mobility platforms to support real-time management of roads. The authors also encourage the use of predictive maintenance policies and better data sharing between agencies. This approach supports safer, longer-lasting, and more sustainable road networks.

Based on the above, I consider the dissertation work of Indira Malikovna Orman on the topic "Development of Algorithms and Software for Determining the Electromagnetic Parameters of an Inclusion in the Environment" to meet the requirements established for dissertations submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D06101 - "Computer Science, Computer Engineering, and Control, and its author to be fully deserving of the conferment of the desired degree in this field.

Foreign Scientific Supervisor:

Amir Mosavi
Associate Professor
Obuda University

ÓBUDAI EGYETEM Neumann János Informatikai Kar Budapest

Supported by:

György Eigner PhD
Dean