Kraków 18.05.2021 r.

Department of Geoinformatics and Applied Computer Science

Faculty of Geology, Geophysics and Environmental Protection

AGH University of Science and Technology

Doctoral Thesis

Application of global optimization methods for solving the joint inversion problem in Pareto mode for selected geophysical data

Author: mgr inż. Katarzyna Miernik

Advisor: dr hab. inż. Tomasz Danek, prof. AGH

This doctoral dissertation aims to solve the joint inversion problem in Pareto mode for at least two types of geophysical data using selected global optimization methods. In order to accomplish this a software MARIA (*Modular Approach Robust Inversion Algorithm*) was created with enough flexibility to give the possibility of replacing the optimization engine as well as the modules realizing forward modelling for particular geophysical methods.

The implementation was divided into three stages. The first one involved the creation of a tool for solving the problem of Pareto joint inversion for gravimetric and magnetotelluric data using an optimization engine based on the PSO (Particle Swarm Optimization) algorithm with the possibility of assigning constraints and introducing the model in the Sharp Boundary Interfaces (SBI) variant.

The gravimetric module was implemented taking into account the superposition principle, where each node of the computational mesh is treated as a rectangle with an assigned density value, and the final result is the sum of the gravitational effect of all mesh nodes. The magnetotelluric module was based on a solution previously programmed in the FORTRAN language, based on the differential approximation method of the Helmholtz equations using the Dirichlet boundary conditions.

The problem of regularization was solved by defining the model in the variant of sharp boundaries as a set of polygons, which significantly simplifies it. Thanks to this approach, a significant reduction in the dimensionality of the solution was achieved, which facilitated the use of stochastic algorithms. The applied Pareto approach eliminated the need for scaling and weighting, assuming that the proposed new solution can only be accepted if it improves at least one objective function without deteriorating any of the others.

The implementation of the first stage was carried out as part of the project entitled "*Innovative technology of petrophysical parameters estimation of a geological media using joint inversion algorithms*" by Geopartner Sp. Z o. o. in cooperation with AGH University of Science and Technology in Krakow and co-financed by the National Center for Research and Development under the number POIG.01.04.00-12-279 / 13. Implementation was done in the C programming language using *gsl* library for numerical calculations and GTK for the graphical interface. The calculations were paralleled on the CPU using OpenMP library. After implementation, tests on synthetic and real data were carried out to prove the correctness of the inversion.

In the second stage the magnetotelluric forward solver was replaced by a magnetometric one. Two tests on synthetic data were performed to confirm the correct operation of the software.

The third stage was to run the inversion in the R environment, using the selected built-in optimization algorithm and properly prepared modules solving forward problems from the previous stage. For this purpose, gravimetric and magnetometric forward solvers were separated and integrated with the R environment. Then multi-criteria optimization was performed in regular and in parallel mode, using the optimization algorithm NSGA2 from the *mco* package. Parallelism yielded a 40 times acceleration. Tests on synthetic data have shown the correct operation of the software.

The joint inversion of the geophysical data in the Pareto mode made it possible to recover the model parameters such as the geometric coordinates of the disturbing body / layers and the density, resistance and magnetic susceptibility of the disturbing body / layer and background without the necessity of weighing and scaling the objective functions.

The study showed that when using potential methods to retrieve information about the geometry of a body lying at a shallow depth, it is much better to analyze the entire set of the obtained models instead of a single one. Due to the possibility of reducing the negative effects of multimodality and equivalence, such an approach seems to be promising.

Functional and domain decomposition in the Pareto inversion algorithm significantly shortens the computation time, which enables the practical use of the code in the comprehensive interpretation of geophysical data.

Considering the significant increase in the number and popularity of global optimization algorithms in recent years, the solution presented in this paper seems to be a promising approach for the future. MARIA 1.0 was developed as commercial software, but it's later 3.0 version, transferred to the R environment, is available on the GIT repository at https://github.com/kamiernik/maria_3.0.git.