Bilbao, November 15th 2018

Mostafa Shahriari has defended his doctoral thesis

The defense has taken place in the Faculty of Science and Technology of the University of the Basque Country, located in the Campus of Leioa

Mostafa Shahriari joined the Basque Center for Applied Mathematics in 2014 as a PhD student within the Simulation of Wave Propagation research line. Previously he had obtained a Bachelor in Applied Mathematics at the University of Kashan (Iran) in 2011 and a Masters in Numerical Analysis at Isfahan University of Technology (Iran) in 2013.

His PhD thesis has been directed by Ikerbasque Research Professor at BCAM-UPV/EHU David Pardo and Shaaban A. Bakr, Assistant Professor from the Department of Mathematics at University of Assiut (Egypt).

On behalf of all BCAM members, we would like to congratulate Mostafa.

Mostafa Shahriari ha defendido su tesis doctoral

La defensa ha tenido lugar en la Facultad de Ciencia y Tecnología de la Universidad del País Vasco, situada en el Campus de Leioa

Mostafa Shahriari se incorporó al Basque Center for Applied Mathematics como estudiante de doctorado en 2014, dentro de la línea de investigación Simulación de la propagación de ondas. Es licenciado en Matemáticas por la Universidad de Kashan (Irán) en 2011 y obtuvo un Máster en Análisis Numérico por la Isfahan University of Technology (Irán) en 2013.

Su tesis doctoral ha sido dirigida por el investigador Ikerbasque en BCAM y la UPV/EHU David Pardo y Shaaban A. Bakr, profesor adjunto del Departamento de Matemáticas de la Universidad de Assiut (Egipto).

En nombre de todo el equipo de BCAM nuestra más sincera enhorabuena a Mostafa.

PhD thesis Title:

Fast One-dimensional Finite Element Approximation of Geophysical Measurements

Abstract:

There exist a wide variety of geophysical prospection methods. In this work, we focus on resistivity methods. We categorize these resistivity prospection methods according to their acquisition location as (a) on surface, such as the ones obtained using Controlled Source Electromagnetics (CSEM) and magnetotelluric, and (b) in the borehole, such as the ones obtained using Logging-While-Drilling (LWD) devices. LWD devices are useful both for reservoir characterization and geosteering purposes, which is the act of adjusting the tool direction to travel within a specific zone.

When inverting LWD resistivity measurements, it is a common practice to consider a one-dimensional (1D) layered media to reduce the problem dimensionality using a Hankel transform. Using orthogonality of Bessel functions, we arrive at a system of Ordinary Differential Equations (ODEs); one system of ODEs per Hankel mode. The dimensionality of the resulting problem is referred to as 1.5D since the computational cost to resolve it is in between that needed to solve a 1D problem and a 2D problem. When material properties (namely, resistivity, permittivity, and magnetic permeability) are piecewise-constant, we can solve the resulting ODEs either (a) analytically, which leads to a so-called semi-analytic method after performing a numerical inverse Hankel transform, or (b) numerically. Semi-analytic methods are faster, but they also have important limitations, for example, (a) the analytical solution can only account for piecewise constant material properties, and other resistivity distributions cannot be solved analytically, which prevents to accurately model, for example, an Oil-Water Transition (OWT) zone when fluids are considered to be immiscible; (b) a specific set of cumbersome formulas has to be derived for each physical process (e.g., electromagnetism, elasticity, etc.), anisotropy type, etc.; (c) analytical derivatives of specific models (e.g., cross-bedded formations, or derivatives with respect to the bed boundary positions) are often difficult to obtain and have not been published to the best of our knowledge.

In view of the above limitations, we propose to solve our forward problems using a numerical solver. A traditional Finite Element Method (FEM) is slow, which makes it unfeasible for our application. To achieve high performance, we developed a multiscale FEM that pre-computes a set of optimal local basis functions that are used at all logging positions. The resulting method is slow when compared to a semi-analytic approach for a single logging position, but it becomes highly competitive for a large number of logging positions, as needed for LWD geosteering applications. Moreover, we can compute the derivatives using an adjoint state method at almost zero additional cost in time. We describe an adjoint-based formulation for computing the derivatives of the electromagnetic fields with respect to the bed boundary positions. The key idea to obtain this adjoint-based formulation is to separate the tangential and normal components of the field, and treat them differently. We then apply this method to a 1.5D borehole resistivity problem. Moreover, we compute the adjoint-state formulation to compute the derivative of the magnetic field with respect to the resistivity value of each layer. We verify the accuracy of our formulations via synthetic examples.

When simulating borehole resistivity measurements in a reservoir, it is common to consider an Oil-Water Contact (OWC) planar interface. However, this consideration can lead to an unrealistic model since, in the presence of capillary pressure, the mix of two immiscible fluids (oil and water) often appears as an OWT zone. These transition zones may be large in the vertical direction (20 meters or above), and in context of geosteering, an efficient method to simulate an OWT zone can maximize the production of an oil reservoir. In this work, we prove that by using our proposed 1.5D numerical method, we can easily consider arbitrary resistivity distributions in the vertical direction, as it occurs in an OWT zone. Numerical results on synthetic examples demonstrate significant differences between the results recorded by a geosteering device when considering a realistic OWT zone vs. an OWC sharp interface.

As an additional piece of work of this Ph.D. Dissertation, we explore the possibility of using a Deep Neural Network (DNN) to perform a rapid inversion of borehole resistivity measurements. Herein, we build a DNN that approximates the following inverse problem: given a set of borehole resistivity measurements, the DNN is designed to deliver a physically meaningful and data-consistent piecewise one-dimensional layered model of the surrounding subsurface. Once the DNN is built, the actual inversion of the field measurements is efficiently performed in real time. We illustrate the performance of a DNN designed to invert LWD measurements acquired on high-angle wells via synthetic examples.