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On the inversion of cross-hole resistivity data

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The data processing of cross-hole resistivity data, for monitoring dynamic process in contaminated site, requires high accuracy in taking into account the effect of the boreholes and electrodes. We developed an approach for inversion of amplitude and phase of electrical data to model the effects of the presence of boreholes and electrodes (in boreholes); this improvement with respect to the conventional approaches allows a more rigorous control of the electrodes and borehole effects on the inversion process with appreciable advantages when the electrodes' size is no longer negligible with respect to their distance, as this often occur in cross-hole survey.
The approach has been implemented on a software code based on the NES-GeoElectric library, that this allows the reconstruction of 2D and 3D electric impedance data optimized for speed and for parallel operation on multi-core computing architectures. The library provides all the core functionalities needed for reconstruction and customizations that have been developed for the specific application to subsurface imaging, including, for example, functions for automatic mesh generation. The in-phase and the in-quadrature component of the measured data is processed, reconstructing a tomographic image of the complex resistivity in the domain of interest; in cross-hole investigation a finite element irregular mesh (FEM) can be customised by the user and computing simulated apparent impedances The mesh is used internally for the reconstruction of the electrode configuration. As the use of a FEM mesh to model the forward problems, especially in 3D problems, can result in meshes with a significant number of nodes, performance considerations should be taken into account and optimizations have been made.
The approach considers the propagation of the uncertainty in the measurements in the model parameter solutions accounting for the covariance matrix of the measurements. Reconstruction is based on a non-linear least squares formulation, which is optimal in the presence of Gaussian uncertainties. We are evaluating, additionally to the use of a least absolute values formulation, which reduces significantly the sensitivity to data outliers. In this second case special optimization routines have been developed based on a Primal Dual – Interior Point Formulation, as the objective function is not differentiable in all the domain.
The reconstruction uses a Tikhonov style regularization, where the regularization matrix is a discretization of the Laplacian operator, with anisotropic smoothing. A priori information, as for instance the preferential elongation of the main geological features (horizontally or vertically) can be controlled by the user, specifying the anisotropic ratio for the horizontal/vertical smoothing.
This approach has been successfully applied to process impedance data of several controlled experiment on lab scale (Comina, 2005), where the electrodes effect on the final inversion results required a rigorous modeling, and also in processing of data sets collected in the field . The benchmark was done by comparing solution of the same data sets, collected at the hydrocarbon contaminated site of Trecate (North-West of Italy), coming from different inversion software. Measurements were carried out with an AC georesistivimeter (PASI Polares) in cross-hole configuration using pole-dipole array with a sequence of about 1200 measurements. The real part of the complex resistivity output from the Polares was inverted with different softwares (e.g. Res2DInv, R2), and qualitatively compared with result from NES. While preserving the global shape of the resulting image, NESGeoelectric tends to limit such high resistivity contrasts between adjacent zones in the considered domain; this is important to avoid misinterpretation when noisy data are present.

Binley, A. 2010, Free Resistivity Software R2 version 2.6 Generalised 2-D Inversion of Resistivity Data http://www.es.lancs.ac.uk/people/amb/Freeware/freeware.htm

Borsic A., Comina C., Foti S., Lancellotta R. and Musso G., 2005, Imaging heterogeneities in sand samples with Electrical Impedance Tomography: laboratory results. Geotechnique, 55, 539-647.