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Parallel three-dimensional electrical capacitance data imaging using a nonlinear inversion algorithm and L^p norm-based model regularization

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Abstract

In order to improve image reconstructions, different classes of nonlinear inversion algorithms are developed and used in different research topics like imaging processes in oil industry or the characterization of complex porous media or multiphase flows. These algorithms are able to avoid local minima and to reach more adapted minima of a given misfit function between observed/measured and computed data. Techniques as different as electrical, ultrasound or potential methods, are used. We present here a nonlinear algorithm that allows us to produce permittivity images by using electrical capacitance tomography (ECT). ECT is a non-invasive technique to image non-conductive permittivity distributions and is used in many oil industry imaging applications such as multiphase flows in pipelines, fluidized bed reactors, mixing vessels, and tanks of phase separation. Even if the ECT technique provides low resolution reconstructions, it is cheap, robust and very fast when compared to other imaging tools. In this method one or more rings of electrodes excite a medium to be imaged at high frequencies, and more particularly at frequencies for which a static electrical potential field has fully developed. In many studies of other research groups only one ring of sources is introduced but the reconstruction accuracy was not totally satisfactory due to the 3D nature of the problem to be solved. Instead of using nonlinear stochastic algorithms like the simulated annealing (SA) technique that we optimized in previous studies to image permittivity distributions of granular or solid materials as well as real oil-gas or two-phase flows in 2D cylindrical vessel configurations, we propose here a new ECT inversion tool to image permittivities in a 3D cylindrical configuration. 3D stochastic optimization methods such as SA, neural networks, genetic algorithms can become computationally too prohibitive, and classical local or linear inversion methods excessively smooth images in many cases. Therefore, we propose here a 3D parallel inversion procedure with different numbers of rings and different L^p norms, with $1 < p \leq 2$, applied to the model regularization of the misfit function to increase the resolution of the models after inversion. We are able to better reconstruct two-phase and three-phase (oil, gas and solids) mixtures by combining L^p -norm regularizations of the misfit function to minimize and several rings of electrodes. All these algorithms have been implemented in a more general parallel framework TOMOFAST-X designed for multi-physics joint inversion purposes, and could also be used in other fields of research such as larger-scale geophysical exploration for instance.

Keywords: Electrical Capacitance Tomography for non-destructive imaging, Non-linear Inverse problem

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