Full Waveform Inversion with Nonlocal Similarity and Adaptive Sparsity-Promoting Regularization in the Gradient Domain

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Seismic inversion is a highly nonlinear and ill-posed problem. In a typical seismic survey, aperture size, source frequency bandwidth, and source and receiver distribution are limited. Therefore, the inversion results usually suffer from strong artifacts and reduced resolution.

In this study, we propose a novel full waveform inversion (FWI) method with a nonlocal similarity prior and adaptive sparsity-promoting regularization in the gradient domain. First, we invoke a self-similarity between patches extracted from a single velocity model. In other words, these patches have a certain level of redundancy. To exploit this property, we adopt a regularization term that finds and stacks together the k most similar patches into a 3D cube for each patch from the velocity model, and then require that the cube be sparse under a 3D orthogonal sparsifying transform. A second regularization term is a generalization of total variation with learning-based dictionaries, which provide a good estimation of the gradient field. Since the gradients emphasize high-frequency components of the velocity model, a better reconstruction of the gradients means a more accurate reconstruction of high spatial frequencies, hence higher resolution.

The proposed optimization problem can be solved by the Alternating Direction Multiplier Method (ADMM), in which the original problem can be transformed into several sub-problems and then be solved by looping through those sub-problems till convergence or for a certain number of iterations. The first sub-problem is similar to the traditional FWI with a quadratic regularization term, which is easily solved by the l-BFGS method with the gradient computed using the adjoint method. The other sub-problems can be solved by hard-thresholding and dictionary learning methods such as K-SVD. We test the proposed method on the BP 2004 velocity model. Compared with traditional FWI, our new technique can better reconstruct sharp edges like salt body boundaries, and is also able to effectively reduce artifacts and noise. Quantitatively, the result from the proposed method has higher structural similarity index (SSIM) and also lower mean square error.