Workshop paper: F07

Wavefield Tomography Based on Local Image Correlations

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SUMMARY

Seismic imaging includes the estimation of both the position of the structures that generate the data recorded at the surface and a model that describes the propagation in the subsurface. The waves recorded at the surface are extrapolated in the model by solving a wave equation, and they are crosscorrelated with a synthetic source wavefield simulated in the same model. Reflectors are located where the source and receiver wavefields match in time and space. If the velocity model is inaccurate, the reflectors are positioned at incorrect locations. We propose an objective function in the image space that does not require common-image gathers (CIGs). We consider pairs of images from adjacent experiments and reformulate the semblance principle in the physical space, instead of the extended space at selected CIGs. We use penalized local correlations of two images to estimate shifts in the image space.

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Seismic imaging includes the estimation of both the *position* of the structures that generate the data recorded at the surface and a *model* that describes the propagation in the subsurface. The waves recorded at the surface are extrapolated in the model by solving a wave equation, and they are crosscorrelated with a synthetic source wavefield simulated in the same model. Reflectors are located where the source and receiver wavefields match in time and space. If the velocity model is inaccurate, the reflectors are positioned at incorrect locations. We propose an objective function in the image space that does not require common-image gathers (CIGs). We consider pairs of images from adjacent experiments and reformulate the semblance principle in the physical space, instead of the extended space at selected CIGs. We use penalized local correlations of two images to estimate shifts in the image space.

Introduction

Wave-equation tomography is a family of techniques that estimate the velocity model parameters from finite bandwidth signals recorded at the surface. The inversion is usually formulated as an optimization problem, where the correct velocity minimizes a certain objective function that measures the inconsistency between the data simulated in a trial velocity model and the observed data. The objective function can be defined either in the data space (full-waveform inversion (FWI) (Tarantola, 1984; Pratt, 1999)) or in the image space (migration velocity analysis (MVA)). MVA (Fowler, 1985; Al-Yahya, 1989) defines the objective function in the image space and is based on the semblance principle (Al-Yahya, 1989). If the velocity model is correct, the images from different experiments must be consistent since a single earth model generates the recorded data. MVA leads to smooth objective functions and well-behaved optimization problems (Symes, 1991), and it is less sensitive to the initial model than FWI.

Theory

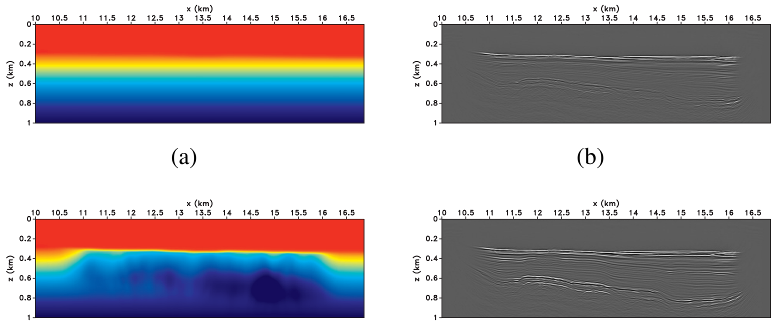
MVA is based on the semblance principle (Al-Yahya, 1989): a single earth model generates the recorded data and if the velocity model is correct, different experiments must produce consistent images of the reflectors. We evaluate the semblance of two images by computing local correlations at each image point and define the objective function

$$\mathcal{J}(m) = \frac{1}{2} \sum_i \| \sum_{\boldsymbol{\lambda}} P(\mathbf{x}, \boldsymbol{\lambda})\, c_i(\mathbf{x}, \boldsymbol{\lambda}) \|^2_{\mathbf{x}}, \tag{1}$$

where $c_i(\mathbf{x}, \boldsymbol{\lambda}) = \int_{w(\mathbf{x})} R_{i+1}\left(\boldsymbol{\xi} - \frac{\boldsymbol{\lambda}}{2}\right) R_i\left(\boldsymbol{\xi} + \frac{\boldsymbol{\lambda}}{2}\right) d\boldsymbol{\xi}$ is the local correlation of the images R_i and R_{i+1} corresponding to shots with index i and $i+1$, and P is a penalty operator that highlights asymmetries of the correlation panels. The correlations are computed over seamless overlapping windows $w(\mathbf{x})$. If the velocity model is correct, the *maximum* of the correlation lies along the reflector slope ; otherwise the maximum of the correlation is displaced from the reflector slope in a direction that depends on the sign and extent of the velocity error . A measure of velocity error is obtained by penalizing the local correlations perpendicular to the reflector slope

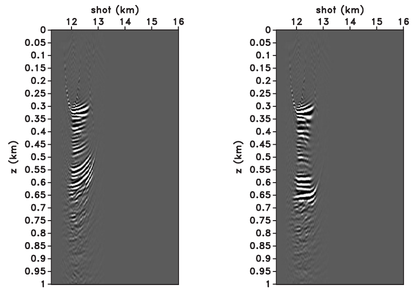
Real data

We test our inversion algorithm on a real dataset supplied by eni E&P. The initial slowness model and migrated image are shown in Figures 1(a) and 1(b). The inversion converges after 60 iterations of steepest descent and returns the model in Figure 1(c) and the migrated image in Figure 1(d). The migrated images are displayed on the same scale. Observe the increased strength of the reflectors after inversion. The common-image gathers in Figures 2 show that, after inversion, the single migrated images locate reflectors at consistent depths and thus the velocity model is kinematically accurate.



(a) (b) (c) (d)

Figure 1: Initial slowness model (a) and corresponding migrated image (b). After 60 iterations, we recover the model in (c); the corresponding migrated image (d) shows improved focusing.



(a) (b)

Figure 2: Shot-domain common-image gathers at $x = 12$ km for the initial model (a) and after inversion (b). The gathers indicate the contribution of each migrated image before stacking.

Conclusions

We present a wavefield tomography approach based on a restatement of the semblance principle in the image space. We define an objective function using penalized local image correlations. This formulation avoids the construction of common-image gathers and the picking of moveout curves. The gradient of the objective function is computed with the adjoint-state method. A real data example proves the effectiveness of our approach.

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