Recent Advances in Data Selection and Data Conditioning for FWI

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Abstract

In the latest years FWI started to be used to improve the velocity models in a commercial way. But it is still an expensive process. In this paper we show the application of batch sampling as a tool to decrease the FWI run time. Moreover, we present the comparison between Gaussian filter and Structural filter used to smooth the gradient field in FWI process. The tests show that batch sampling can reduce the FWI run time without damaging the velocity update, while structural smoothing preserves the geological characteristics in the gradient field.

Introduction

The Full Waveform Inversion concept has been studied since the 80', when it was introduced by Lailly (1983) and Tarantola (1984). Since then, this technique has been refined and applied in different domains as demonstrated by the numerous references available, for example, Pratt (1990), Shin & Ha (2008) and Vigh & Starr (2008).

For many years FWI was developed in the background, since the computational power to implement it in a commercial way was not available. More recently, with advances in the processing capability of computers, companies started to invest on FWI to improve velocity models and consequently to provide better subsurface images. The benefits of FWI using different acquisition geometries have been well documented in the literature. For example, Plessix & Rynja (2010) presented the application of VTI FWI on NAZ dataset; Houbiers et.all (2012) showed examples of FWI on OBC dataset and Vigh et. all (2010) presented FWI application on WAZ data.

Even with all the computational advances, FWI is still expensive from the computational point of view and research has been constantly ongoing to reduce cost. Shot decimation techniques or super-shot grouping are common approaches to decrease the processing time. In this paper we show the application of a hybrid stochastic-deterministic optimization method (Friedlander and Schmidt, 2012) in the FWI process and its benefits to minimize the running time of each iteration in an coil acquisition geometry.

Another challenge faced with the implementation of FWI we approach in this paper, is the gradient smoothing. This step is important to minimize the footprint effects during velocity model updating. Gaussian filter is an option broadly used in seismic imaging, but it tends to denigrate the geological information in the gradient field. Here we present the results of the application of structural-oriented filter (Hale, 2009) and compare then with results using Gaussian filter.

Dataset

The dataset chosen to perform the tests was acquired in an area located in ultra-deep water (~ 2000m water depth) with maximum offset distance approximately 8000m. It has limited low frequency content and low frequency noise is present. The overburden consists of a complex dipping salt-layer up to two thousand meters thick, consisting of both homogeneous halite bodies and layered evaporates. The salt is in turn overlain by Albian carbonates and inter-bedded sands and shales. The complex propagation of the seismic wavefield within this geological environment provides a challenge not only to acquire data which adequately illuminates the reservoir events at depth, but also to create a velocity model that represents the geological complexity of the area.

The dataset contains full-azimuthal coverage obtained by coil acquisition geometry (Moldoveanu et al 2008). The fold of coverage is shown in Figure1. The initial velocity model (Figure 2) was built by using Reflection Tomography followed by smoothing to adjust the model to the 3Hz frequency used during testing. The input data preparation included noise and multiple attenuation.

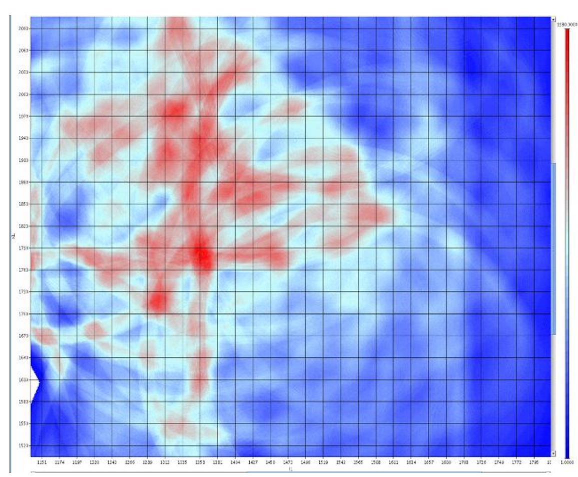

Figure 1: Dataset's fold of coverage. Higher fold represented by red color and lower fold represented by blue color

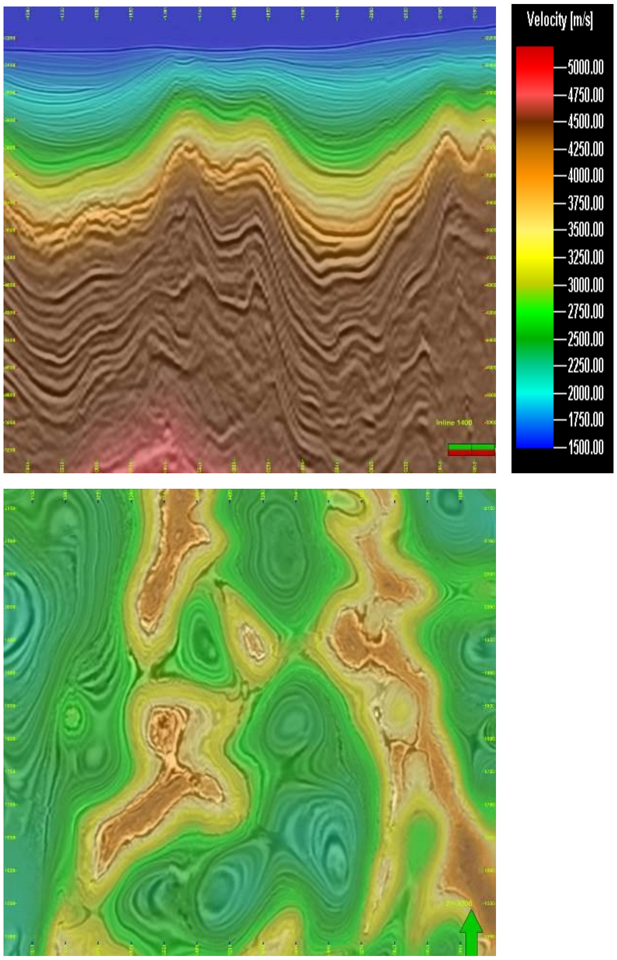

Figure 2: Input velocity model - Inline section on top and depth slice on bottom

Shot Selection

One important requisite to perform FWI is the study of how we will make the process faster without compromising the quality of the results.

One option available consists of selecting a subset of the shots for each internal iteration of FWI. In this case, the number of shots that will be used, as input for each iteration, is user specified, and it is important to make sure that the shot distribution covers survey area.

Super-shotting is a technique in which two or more shots inside of a pre-determined radius are grouped to form a unique single shot gather (Morton et. all, 2008). It is general practice to apply some regularization scheme to compensate for the difference in shot location of the input and super-shot gathers. While this reduces the number of shots to be processed, for some acquisition geometries it can result in unwanted large movement of the shots which cannot be fully compensated for by the regularization scheme.

More recently van Leeuwen & Herrmam (2012) reviewed a hybrid optimization strategy developed by Friedlander and Schmidt (2012), where conventional and stochastic optimizations are combined. This batch-sampling method uses a different, randomly chosen, sequential source at each iteration. The sources are randomly selected inside of a pre-determined radius. At each update the size of the radius decreases, making the batch of sources increases gradually allowing for the iterations to be initially cheap and progress quickly, leading to fast velocity convergence as the batch size grows.

Table 1 shows the percentage reduction in the number of shots for each of the shot decimation strategies mentioned above. For manual selection, we selected every fourth acquired shot. The super-shotting was performed using a radius of 160m which resulted in a RMS shot movement of 57m. For batch sampling we used a radius of 250m.

Table 1: Reduction in the number of shots for different shot decimation schemes

Strategy	% of reduction
Manual shot selection	75
Super-shot	84
Batch sampling	95

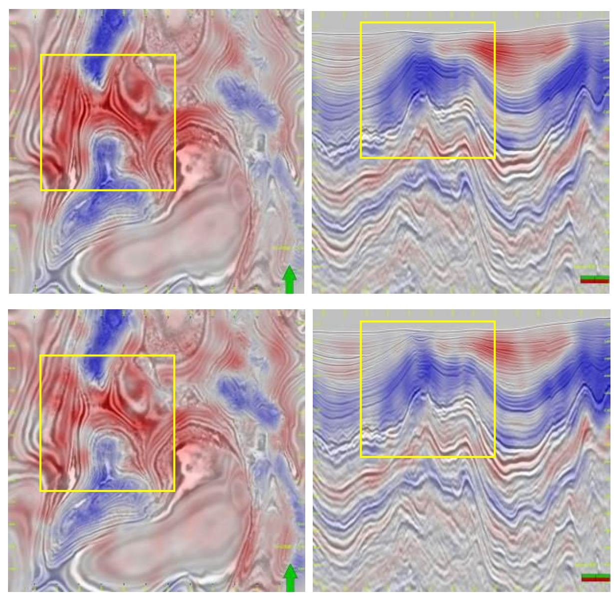

Figure 3: Comparison of Vp update for two shot decimations schemes. Manual shot selection (top) and batch sampling (bottom), depth slice (left) and inline (right).

Figure 3 details a comparison of the Vp update resulting from the manual shot selection method and the batch-sampling method. Note than in the depth slice of Figure 3, the manual selection has higher velocity change values in the area with higher fold (yellow box) than in areas with lower fold. The batch sampling method shows a more uniform update around the survey, decreasing the effects of irregular fold. Moreover, the batch sampling allows us to perform the update gradually, avoiding falling into a local minimum in early iterations. This is possible due to the sparse distribution of the shots selected, which is not fold dependent. Figure 4 details the shot distribution of the batch sampling.

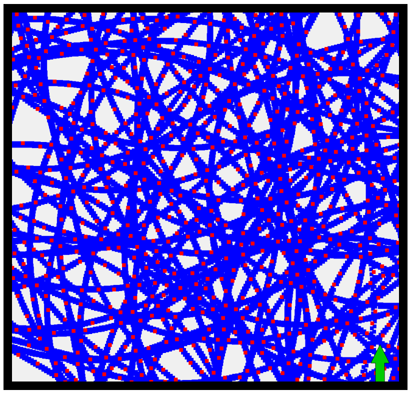

Figure 4: Shot distribution. The blue dots represent the original shots and the red dots represent the shots selected by batch sampling.

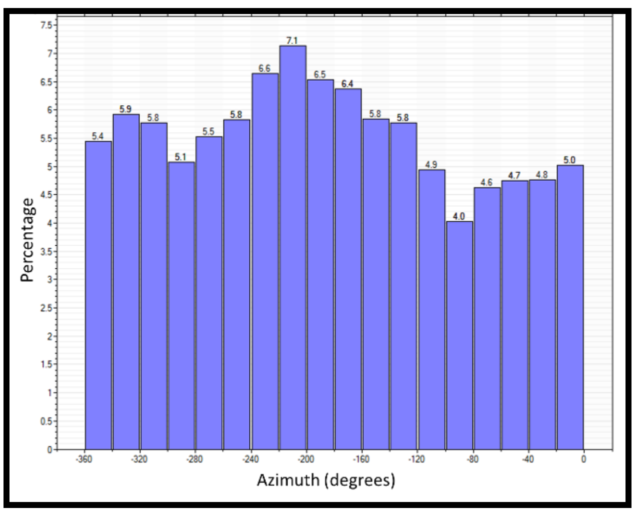

Figure 5: Histogram showing the azimuth distribution of the shots select by batch sampling

Once the batch sampling select the shots randomly, we must make sure the azimuth distribution is preserved after the shot selection. Figure 5 details a histogram of the azimuth values of the shots selected by the batch sampling technique, demonstrating that the re-sampled dataset preserves the full azimuth nature of the acquisition measurement. For each iteration a different set of shots will be selected which contributes to a balanced azimuth distribution as the number of iterations increases.

Structural Smoothing

When we started to use batch sampling a natural concern is about how we can overcome the effects of using few shots in the gradient calculation. In order ensure the updated velocity will not show the effects of footprint caused by acquisition geometry and/or shot decimation, it is necessary choose carefully how to smooth the gradient. In general, Gaussian smoothing is used, because it is easy to implement and computationally cheap. However, sometimes, Gaussian filters are not effective because the shape and orientations of image features vary spatially (Hale, 2009). This kind of images requires filters with an impulse response that varies spatially and anisotropically, in order to preserve their geological characteristics. Hale (2009) presents a structure-oriented bilateral filtering (Structural smoothing) that preserves details within coherent seismic image features. The disadvantage of bilateral filtering is that the computational cost is high compared with Gaussian filters.

Figure 6 compares velocity updates using two gradient smoothing techniques; Gaussian filtering (top) and Structural smoothing (bottom). Comparing the images we can see that the velocity update using structural filter is more geologically consistent then Gaussian smoothing, avoiding, for example, the contamination of the sediment velocity by the salt velocity.

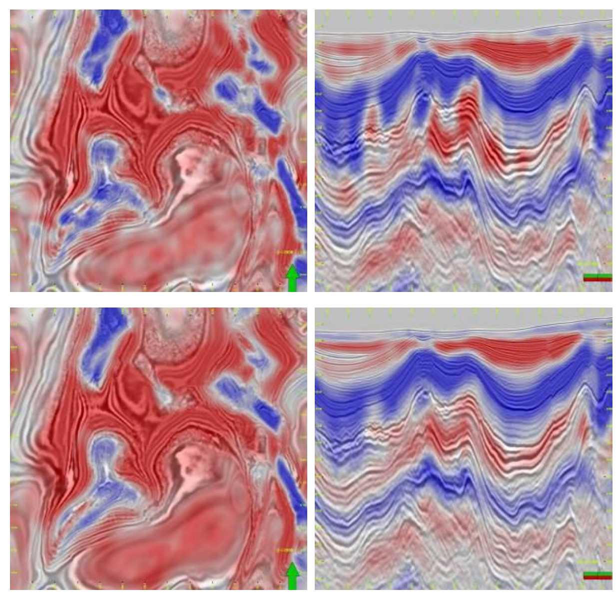

Figure 6: Depth slice (left) and inline section (right) of delta V. Here we compare Gaussian smooth (top) with structural smooth (bottom).

Conclusions

FWI is an expensive technique from the computational point of view. Studies have been performed in order to decrease the run time and to keep the quality of the velocity updates. Another challenge present in the FWI application is how to improve the gradient field conditioning.

In this paper we presented the application of shot selection technique that uses a gradually increasing batch of sources allowing for the iterations to be initially cheap and progress quickly, leading to fast convergence as the batch size grows. The results showed a significant reduction in the number of shots selected without damage the quality of the update. Moreover, we compare the application of Gaussian filter with Structural filter to smooth the gradient field, and the results showed that the structural smooth attenuates the footprint effects without denigrate the geological information in the gradient field.

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