Obstacles to automated velocity analysis

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Abstract

Automated velocity analysis is a desirable seismic processing goal but obstacles still remain. A popular tool for seismic velocity estimation in prestack depth migration is the analysis of “smiles and frowns” on common image gathers. In the time domain, optimizing the stacking process involves Normal Moveout (NMO) velocity analysis. In either case, we can evaluate the alignment of arrivals in these gathers is indicated through the measure of semblance. Indeed, the maximization of semblance in velocity analysis could be viewed as a method for automated velocity analysis. Unfortunately, there are several situations where the maximization of semblance will not lead to the correct velocity. These include the cases of strong multiple arrivals, reverberatory wavelets, effects of anisotropy, static shifts, and the situation with Class 2 amplitude variation with offset (AVO). Many of these problem cases can be solved by processing. However, in practice there is a need for intervention by the interpreter that results in a semi-automated velocity analysis.

Introduction

Velocity analysis with the use of semblance measures has been popular ever since the pioneering paper by Taner and Koehler (1969). The use of semblance as a coherency measure has been effectively utilized in prestack migration and inversion by Symes and Carrazone (1991). In order to understand the application to prestack depth migration, we can revisit the analysis of “smiles and frowns” on common image gathers (CIGs), as described by Zhu, et al. (1998). In this analysis, the goal is essentially to adjust the velocity in order to flatten the smiles and frowns. Yan (2003) and Yan et al. (2004) suggested that this CIG velocity analysis be converted from the depth to the time domain so that the smiles and frowns would have the same zero offset time. Yan also demonstrated the effects of anisotropy on migration/velocity analysis for Alberta Foothills data.

In either time or depth domain the measure of reflected arrival alignment is generally measured by the semblance, as defined by Taner and Koehler (1969). First of all, consider the definition of semblance. Let trace samples be denoted as $y_j(t_i)$, where j denotes the trace number and i denotes the time sample. For a group of M seismic traces over a window of N time samples, the definition of semblance, S_{MN}, is given by:

$$S_{MN} = \frac{\sum_{i=1}^{N}\left[\sum_{j=1}^{M} y_j(t_i)\right]^2}{M\sum_{i=1}^{N}\sum_{j=1}^{M} y_j^2(t_i)} \qquad (1)$$

The semblance is essentially the energy of the sum of trace values divided by the sum of the energy of the traces. Its maximum value is 1.0, and this is achieved when the traces are perfectly aligned. In most (but not all) cases, trace alignment (maximum semblance) will occur when the true velocity is applied.

Attempts to Automate Velocity

The attempts to automate velocity essentially involve the maximization of the semblance for CIGs by use of optimization methods. The techniques can be coupled with prestack depth migration as outlined by Pon and Lines (2004). For the optimization procedure to work, we need to find the correct global maximum of the semblance function by variation of velocity. While there are many situations where this is a straightforward method, there are situations where this oprtimization is not automatic. There are cases where a local maximum can lead us astray as in the case of reverberatory wavelets or statics problems. There are cases where the local maxima or global maximum of the semblance will lead to the erroneous answer, as in the case of strong multiples or Class 2 AVO anomalies (Rutherford and Williams, 1989). There may cases such as anisotropic depth migration where a more general velocity model is needed to handle the correct geophysical situation. In general, the semblance optimization is shown to correctly handle many problem cases such as velocity estimation for noisy data. Nevertheless, although semblance optimization is often robust, one can invent certain cases to defeat its implementation in automated manner. This paper explores these misleading cases and offers possible solutions for the optimization problems.

Conclusions

The automation of velocity analysis by semblance maximization is a desirable goal. Unfortunately, there are many difficulties involved with its implementation. We summarize the problems for semblance optimization in Table 1. Many of these may have processing solutions, such as predictive deconvolution for multiples, wavelet deconvolution, anisotropic velocity analysis, and statics corrections. However, there are also some cases that involve polarity changes with offset, such as Class 2 AVO anomalies, that have no immediate solution other than their recognition in the interpretation process.

Table 1: A Comparison of Semblance Optimization Problems.

Semblance Problem	Solution	Degree of Difficulty
Reverberatory Wavelet	Wavelet deconvolution	Mild
Multiple Interference	Predictive deconvolution or other multiple suppression methods	Medium – worst for water bottom multiples
Anisotropy	Anisotropic imaging methods	Medium – worst for dipping shales
Static shifts in arrivals	Statics corrections in processing	Mild-Severe, very area dependent
Additive noise	Noise suppression prior to velocity analysis	Usually mild, due to robust nature of semblance estimation
AVO effects	Inspection and use of amplitude envelopes	Class 2 AVO anomalies pose severe problems for stacking

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