Through a glass darkly: improving raypath interferometry

David C.Henley
CREWES, Geoscience Department, University of Calgary

Summary

The processing technique known as raypath interferometry was developed as an alternative to conventional statics corrections methods in areas where statics assumptions are violated. It has been successfully demonstrated on several different sets of model and field seismic data. Here, we test an alternative scheme for creating the reference wavefield, or 'pilot traces' used in the interferometry, and we demonstrate the use of the Snell Transform, a modified Radial Trace Transform, for mapping the raw seismic data into the common-raypath domain utilized by raypath interferometry.
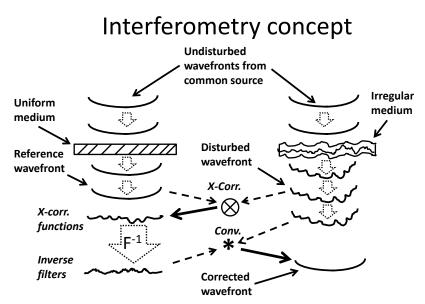
For pilot trace creation from raw data gathers, we find that singular value decomposition (SVD) methods can be used as an alternative to lateral smoothing, but that this method, like lateral smoothing, operates best when lateral structure and discontinuities are first reduced by 'brute force' techniques like horizon flattening and 'trim' statics.
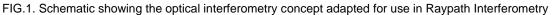
The Snell Transform, because its sampling trajectories are more likely to map seismic data at all depths onto realistic raypath trajectories, appears to lead to slightly better interferometric images, especially at shallow depths, than the Radial Trace Transform; but trial and error are needed to set parameters appropriately.

Introduction

Interferometry instead of trace shifting

Interferometry is a family of wave propagation techniques widely used in the physical sciences to perform imaging or image corrections, or to characterize the media through which waves are propagated. Over the past few years, we have developed a processing technique, based partly on interferometric principles, that allows us to correct seismic data for the image disturbances caused by the irregularities of the near-surface layer. This technique, called 'raypath interferometry', was developed as an alternative to conventional residual statics methods, and generalizes some of the more restrictive assumptions associated with those methods. This generalization enables raypath interferometry to deal with near-surface conditions, like high-velocity surface layers, multi-path reflection arrivals, and non-stationary statics, which clearly conflict with residual statics assumptions (Henley, 2012). All of these conditions were encountered during the first successful application of the method to field seismic data in the MacKenzie Delta (Henley, 2012). This difficult example also highlighted the importance of the reference wavefield estimation process for the success of this particular form of interferometry. Figure 1 schematically portrays the optical interferometric process that we simulate. Our current method for reference wavefield estimation, running trace averaging, represented in the figure by wavefront transmission through a uniform medium, is only one possible scheme; this paper examines a potential alternative—Singular Value Decomposition.

Interferometry concept

FIG.1. Schematic showing the optical interferometry concept adapted for use in Raypath Interferometry

Raypath-consistency instead of surface-consistency

The other departure of raypath interferometry from convention is the generalization of the concept of surface-consistency to 'raypath-consistency' to allow the technique to handle seismic data for which the irregularities of the near surface cause wavefront disturbances which are neither surface consistent, nor stationary (uniform in time). Regions where the velocity of the near-surface layer approaches or exceeds that of underlying sediments are notorious for yielding such data. We have previously shown examples of seismic data from such regions (Henley, 2004, 2007, 2012), and have demonstrated the raypath interferometric solution for one of them (Henley, 2012). It has recently been shown by Cova et al (2014) that another situation in which nonstationarity of statics can arise is the shear-wave leg of converted wave data, where the lateral displacement of the conversion point with depth leads to significant variation of the near-surface raypath angle of emerging shear waves. This circumstance has been observed and compensated both on model data (Cova et al, 2014) and on field data (Henley, 2012, 2014). The violation of surface-consistency led us to the alternative, more general constraint called raypath-consistency. Accessing the near-surface raypath angle for the process of near-surface correction, however, requires the raw input seismic data to be transformed to a domain in which one of the coordinates represents raypath angle. While our first choice, the Radial Trace Transform, has been quite successful in practice, there are other, possibly even more effective alternatives. We demonstrate one of these, the Snell Transform, in this paper, and Cova et al (2015) demonstrate another alternative, the Tau-P Transform in their paper.

Details and Results

Reference wavefield estimation

Most forms of seismic interferometry are based on cross-correlations of pairs of raw seismic traces (Bakulin and Calvert, 2006), which are summed over common surface location and used to estimate a Green's Function corresponding to that location. We, on the other hand, take an alternate approach, more akin to the optical interferometry portrayed in Figure 1, in which we sum raw traces, *then* correlate the sum with individual raw traces. The individual correlation functions can be used either as matched filters to correct their corresponding raw traces by correlation, or they can be used to derive inverse filters to correct the corresponding traces by convolution. By directing the raw trace summation process along reflecting horizons and force-aligning adjacent traces, the summation process gives a good estimate of the propagating signal waveform. Underlying lateral geological variations are averaged out by the process, thus simulating an undisturbed 'reference wavefield'. Correlating raw traces with the traces of the reference wavefield yields cross-correlations or 'surface functions' which contain timing and phase

information primarily associated with the surface locations and raypath parameters of the raw traces. Because we use the entire cross-correlation function for each raw trace, we can apply not only a bulk shift (static correction), but the phase adjustments needed to compensate for complexity in the reflection arrival waveform (multi-path arrivals, scattered arrivals, for example).

In our original processing flow, the reference wavefield estimation for a gather of traces is accomplished by flattening the gather relative to an interpreted horizon followed by trim statics and running trace averaging. Here, we compare an alternative method consisting of horizon flattening followed by Singular Value Decomposition (Yedlin, 2012) and median smoothing. Figure 2 shows a raw common-raypath PP trace gather from the Hussar 3C survey (Margrave et al, 2011) and its corresponding running-averaged reference wavefield estimate, while Figure 3 shows the same raw trace gather and its SVD-derived reference wavefield estimate. These estimates are so similar that cross-correlations of either one with the original raw trace gather are also very similar, and the final CMP stack results for the two estimation techniques are indistinguishable.
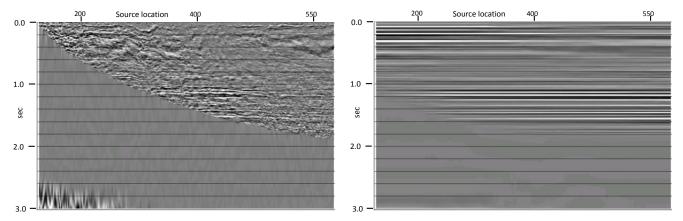

FIG. 2. Raw PP common-raypath gather from Hussar 3C survey (left), and its reference wavefield estimated by horizon-flattening and running trace averaging (right).
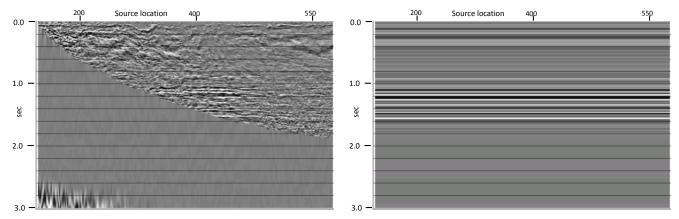

FIG. 3. Raw PP common-raypath gather from Hussar 3C survey (left), and its reference wavefield estimated by horizon-flattening and SVD (right).

Raypath domain transform

In previous work, we have used the Radial Trace Transform to map X-T trace gathers to an approximate raypath-dependent domain, a conscious simplification. A raypath schematic for a trace in this domain is shown in Figure 4 (left), where raypath angles are constant and equal in all layers, and therefore do not honor Snell refraction at interface boundaries. An alternative to the standard radial trace transform, however, is the 'Snell' transform, described by Claerbout (1975, 1985) and Ottolini (1982) in connection with the RT transform. In the Snell transform, the trajectories for sampling an input trace gather are bent

or curved, rather than being linear, as in the RT transform. The bending or curvature is determined by the nominal interval velocity structure of the earth, so that each sampling trajectory approximately obeys Snell's law at each major reflecting boundary in the earth, thus approaching the raypath schematic in Figure 4 (right), and more nearly corresponding to a true raypath-domain transform. Figure 5 compares the Common Conversion Point (CCP) stack of the PS component from the Hussar 3C survey (Margrave et al, 2011) obtained first using the standard RT transform (left) in the raypath interferometry with a CCP stack obtained using the Snell Transform (right). While the results are similar, it appears that the Snell Transform, with its closer resemblance to actual raypaths leads to stack image results where the shallow events, in particular, are more coherent and more highly resolved than those obtained using the ordinary RT transform. A drawback is the requirement to supply the Snell Transform with velocity information, perhaps on a trial and error basis.
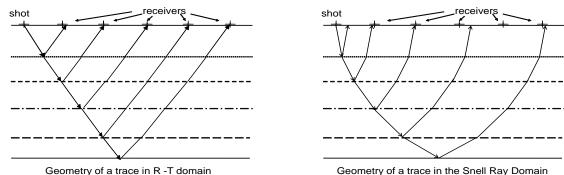

FIG. 4. Raypath schematic for RT trace (left) and for Snell Ray trace (right). Snell Ray traces more likely simulate true raypaths.
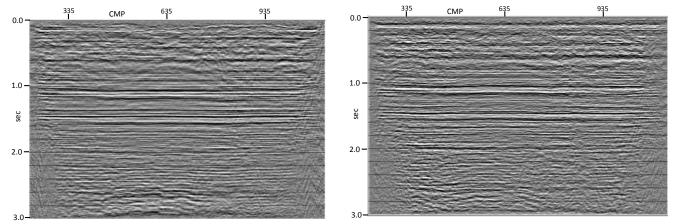

FIG. 5. CCP stacks for Hussar 3C data (PS component) using the RT transform (left) and the Snell Ray Transform (right), respectively, in the raypath interferometry.

Conclusions

Reference wavefield estimation

For reference wavefield estimation, SVD methods may be used as an alternative to running trace averaging; horizon flattening should precede either technique.

Raypath domain transform

While the radial trace (RT) transform works well to transform data to an approximate raypath-dependent domain, the more realistic Snell Transform appears to improve final stack image results, particularly for shallow events, where raypath-dependence is likely most significant.

Acknowledgements

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