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Abstract

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ORIGINAL RESEARCH

Signal enhancement and multiple suppression using Radon transform: an application to marine multichannel seismic data

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Abstract Radon filters are often used for removal of multiple reflections from normal move-out-corrected seismic reflection data. In the conventional Radon transform, integration surfaces are hyperbolic rather than linear. This specific hyperbolic surface is equivalent to a parabola in terms of computational expense, but more accurately distinguishes multiples from primary reflections. The forward transform separates seismic arrivals by their differences in travel time move-out. Multiples can be suppressed by an inverse transform of the seismic data. Examples show that multiples are effectively attenuated in pre-stack and stacked seismograms. Based on the parabolic Radon transform, a new method is utilized for missing offset restoration, resampling and regularization of pre-stack individual common depth point (CDP) gathers. The method is also valid for resampling spatially aliased seismic data. Restoration of missing offsets and trace interpolation is an interesting and important problem in seismic data processing. Here we present an application of Radon transform on a multichannel seismic data set from the western continental margin of India (WCMI), which shows remarkable signal enhancement.

Keywords WCMI · Multichannel seismic data · Radon transform · Multiple suppression · Restoration

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Introduction

The Radon transform is a mathematical technique that has been widely used in seismic data processing and image analysis. This will typically transform the data from the space-time domain (x, t) to the tau-p domain (τ, p), where it is modified and then transformed back to (x, t) space. Three types of Radon transforms can be used for multiple-attenuation in seismic data processing. The slant-stack or τ-p transform, the hyperbolic Radon transform and the parabolic Radon transform (Trad 2001). The slant-stack transform can be combined with predictive deconvolution to attenuate multiples in the pre-stack seismic data based on the periodic characteristic of multiples. In contrast to the slant-stack transform, the hyperbolic and parabolic Radon transforms are applied to the attenuation of multiples based on move-out discrimination between multiples and primaries.

Radon transform was first introduced by Johan Radons (1917). Deans (1983) discussed the mathematical theory, and Durrani and Bisset (1984) examined the fundamental properties of the Radon transform. Thorson and Claerbout (1985) utilized the hyperbolic Radon transform as a velocity analysis tool, and the parabolic Radon transform was applied for the first time as a multiple attenuation technique by Hampson (1986). Since then Radon transforms have become one of the most widely used approaches in attenuating multiples in seismic reflection data (Bradshaw and Ng 1987; Kelamis et al. 1990; Kostov 1990; Foster and Mosher 1992; Hugonnet and Canadas 1995; Sacchi and Ulrych 1995; Cary 1998; Sacchi and Porsani 1999; Oppert 2002; Trad et al. 2002, 2003; Ng and Perz 2004). Radon transform-based multiple suppression schemes are fundamentally limited by the transform's ability to resolve different events on the basis of move-out differences. This is particularly true for inter-bed multiples.

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Because seismic data consists of a finite number of discrete observation points, a least-squares solution of the transform, rather than the classical formulation, improves the resolution (Thorson and Claerbout 1985).

The ultimate goal of seismic exploration in the hydrocarbon industry is to generate accurate images of the subsurface geology to identify hydrocarbon-bearing structures. Seismic data processing plays an important role in achieving this goal. One of the key problems in seismic data

input ensembles. The forward and inverse transforms are performed in the frequency domain, independently for each frequency. Two inversion schemes have been developed for the least-squares forward transform. Assuming that both the parameters in the model space and the noises in the data space have Gaussian distributions leads us to use a linear least-squares inversion scheme, known as as the Toeplitz inversion (Hampson 1986; Beylkin 1987; Kostov 1990; Zhou and Greenhalgh 1994). It is called so because the ing this goal. One of the key problems in seismic data processing is to attenuate multiple reflections from seismic data. Different approaches have been investigated and applied to the multiple attenuation problem, including the Radon transform, which is an industry standard and which has also been attracting the attention of the scientific community during the last two decades.

In this paper, we demonstrate the application of a parabolic transform method called the parabola move-out time at reference offset (PRADMUS) for suppressing multiples in seismic data processing. The PRADMUS, which is a tool of FOCUS, a commercial seismic data processing software package, incorporates two of the discrete Radon transform methods, namely the parabolic Radon transform, which is designed primarily to model and subtract multiple energy, and the linear Radon transform, which is designed primarily to attenuate the linear events from seismic records or for predictive deconvolution in the tau-p domain. The parabolic option performs a band-limited parabolic Radon transform on input gathers that have been corrected for normal move-out. After forward transform, the program zeros a zone of user-specified primary energy, performs an inverse transform on the remaining multiple energy, and subtracts the resulting gather from the original data to produce the signals without multiples.

Methods

The tau-p deconvolution techniques can be used to attenuate relatively short period multiples. The time domain multiples show increasingly poorer temporal periodicity with increasing offset, i.e., (the events are converging at far offsets so they are not periodic). In the tau-p domain the multiple energy is periodic—although the period reduces with increasing slowness. By applying the deconvolution in the tau-p domain and then applying an inverse tau-p transform the data are returned to the $x - t$ domain.

PRADMUS transforms the data into the tau-p domain. Tau and p are coefficients defining the intercept time and the curvature of parabolic curves of normal move-out (NMO)-corrected events in the input ensembles. PRADMUS first performs a least-squares forward transform. The forward transform followed by the inverse transform without any filter in between yields a least-squares approximation to the Zhou and Greenhalgh 1994). It is called so because the operator matrix in this inversion scheme has a Toeplitz structure (Duijndam 1988; Kostov 1990). Therefore, only one column of the matrix needs to be formed and the system of linear equations can be solved with a fast recursive Levinson algorithm suggested by Kostov (1990) for the model space parameters.

The Toeplitz inversion is carried out independently for each frequency. Assuming the noises in the data space have a Gaussian distribution and the model space parameters have a Cauchy distribution yields a non-linear iterative least-squares inversion scheme. This inversion scheme is able to produce a tau-p panel in which the energies of parabolic events are better focused and less smeared compared with the tau-p panel obtained through the Toeplitz inversion. This inversion scheme is denoted as sparse inversion and is able to produce a high-resolution parabolic Radon transform. It is a non-linear inversion problem, and hence the inversion has to be implemented as an iterative linear inversion problem. Within each iteration, the model space parameters obtained from the previous iteration are used as the initials for the true model parameters.

The inversion uses the direct transpose or adjoint forward parabolic Radon transform as the initial estimate of the model space parameters for the first iteration. A cost function is used to stop the iterations at its local minimum. This non-linear inversion is also carried out for each frequency independently. The sparse inversion can produce a high-resolution tau-p panel. With the high-resolution transform, the collapse of parabolic events in the tau-p domain may better separate the primary energies and multiple energies, in favor of better multiple elimination and primary preservation. The sparse inversion can be achieved by supplying hires to the parameter method. Because the sparse inversion is implemented iteratively, it is significantly slower than the Toeplitz inversion. The processing procedure includes the following steps:

Forward transform: The forward transform decomposes the NMO-corrected seismic data into a sum of parabolic events. The primary events may differ from other coherent energies, such as multiples and ground rolls, by the curvature (move-out) of the parabolas.

Filtering: The program designs and applies a filter to the transformed data in the tau-p domain in order to

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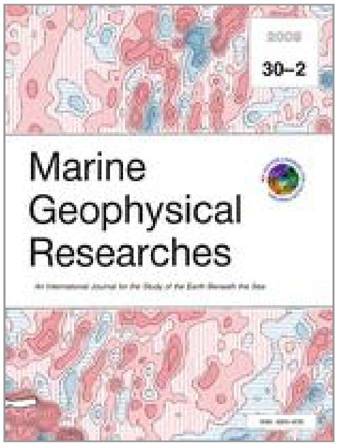
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