PAPER K

RESTORATION OF FAR OFFSET CROSS-WELL TRAVELTIMES

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ABSTRACT

An efficient means of recovering far offset travel time for cross-well seismic tomography can be obtained by constructing traveltime hyperbolas in the Radon transform domain from the source-receiver projection matrix. The process consists of two steps: (1) estimate a localized slowness by taking the average in each illuminating view for several gathers; and (2) predict missing data using estimated slowness via Radon transform. Efficiency is obtained by manipulating the travel time hyperbolas in the projection matrix. Results obtained for both synthetic and field data demonstrate that the restored travel time picks are very close to the actual values.

INTRODUCTION

In the cross-well seismic data acquisition, the source and receiver positions are often restricted to certain relatively close to vertical offsets, because of limited source energy and the cost of field operations. In such surveys, the ray paths are predominantly horizontal. In another words, the available data in the source-receiver projection matrix is a diagonal strip such as illustrated by the shaded zone in Figure 1. Since the far offset data significantly influences horizontal resolution of the image reconstructed from the cross-well geometry, the restoration of missing data outside this strip are very important. In addition, abrupt absence of these large offset projection (travel times) can often result in unsightly artifacts in your inversion or image reconstruction.

Data restoration has been an issue in image processing and the physical sciences for some time. Many kinds of algorithms have been implemented. (Gerchberg, 1979, Jain, 1981) Two common drawbacks of these algorithms are instability for data with noise and the requirement for heavy computation. In this paper, we report a method and related extrapolated ray path. Notice that the CSP and CRP are end members of the collection of CLP gathers. The procedure is schematically illustrated in Figure 1a and 1b.

The Radon transforms not only holds the key for tomographic reconstructions but also offers significant advantages for general image representation and manipulation. We use the same Radon transform mechanisms as performed in inversion to predict the far offset data. The Radon transform pair can be defined as (Jain, 1989)

$$t(p,\theta) = \iint f(x,z)d(x\cos\theta + z\sin\theta - p)dxdz \tag{1}$$

$$f(x,z) = \frac{1}{2\pi^2}\int_0^{\pi}\int_{-\infty}^{\infty} \frac{\partial t(p,\theta)/\partial p}{x\cos\theta + z\sin\theta - p}\, dp\, d\theta \tag{2}$$

where $t(p,\theta)$, $f(x,z)$ and $\partial t/\partial s$ represent the traveltime, slowness field, and the average slowness respectively. In practice, instead of parallel beams, fan-beams are used to collect cross-well traveltimes as shown in Figure 2.

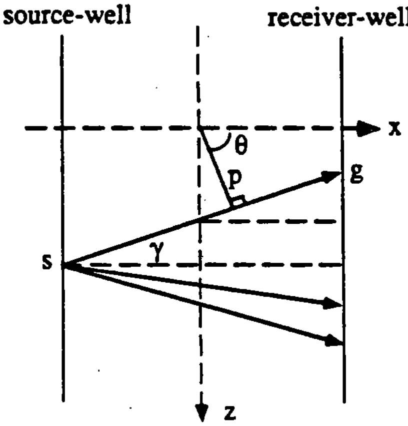

Fig.2 Cross-well projection geometry

To derive the inverse Radon transform for cross-well fan-beams, we define the following coordinate transform :

$$p = \frac{s+g}{2}\frac{x_0}{\sqrt{x_0^2+(s-g)^2}} \tag{3}$$

$$\theta = tg^{-1}\frac{x_0}{s-g} \tag{4}$$

$$\hat{f}(x,z) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} w(s,g')\partial T/\partial L \; ds = \sum_{S}^{N} w(s,g')\partial T/\partial L \tag{9}$$

In practice, it would yield a poor estimate for f(x, z) because of the limited number of contributing data. In order to improve this estimate, we use the average of the each view, e.g., each CLP. That is, each integral contribution from Eqn. (8) for the same CLP is used to estimate the local slowness, i.e.,

$$\hat{f}(x,z) = \frac{1}{N}\sum_{n=1}^{N} \frac{1}{M}\sum_{m=1}^{M} \partial T/\partial L \tag{10}$$

and then to predict the missing data for source and receiver gathers:

$$\hat{t}(s_m,g_m) = \iint f(x,z)\delta(x\cos\theta(s_m,g_m) + z\sin\theta(s_m,g_m) - p(s_m,g_m))dxdz \tag{11}$$

The improved estimate obtained by including the far offset data $\hat{t}(s_m,g_m)$ becomes

$$\hat{f}(x,z) = \frac{1}{N}\sum_{n=1}^{N} \frac{1}{M}\sum_{m=1}^{M} \partial T/\partial L + + \frac{1}{N'}\sum_{n=1}^{N'} \frac{1}{M'}\sum_{m=1}^{M'} \partial \hat{T}/\partial L \tag{12}$$

The image $\hat{f}(x, z)$ is still not fully reconstructed because of the limited number of views in the survey. In other words, the well lines are too short to deploy as many sources and receivers as desirable. Instead, other algorithms in which additional constraints can be incorporated should be used (Harris, 1991). Here we use the mechanism of the inverse Radon transform only for restoring the missing far offset data.

ALGORITHM AND EXAMPLES

The implementation of Eqn. (10) is equivalent to constructing traveltime hyperbolas with estimated slowness values taken from a Radon transform applied to the source-receiver projection matrix. Common-receiver, common-source and common-lateral point gathers are defined, respectively, as

Comparing Fig. 3c with Fig. 3a, we see the recovered picks are very similar to the original with an average difference error of only 0.073 mSec.

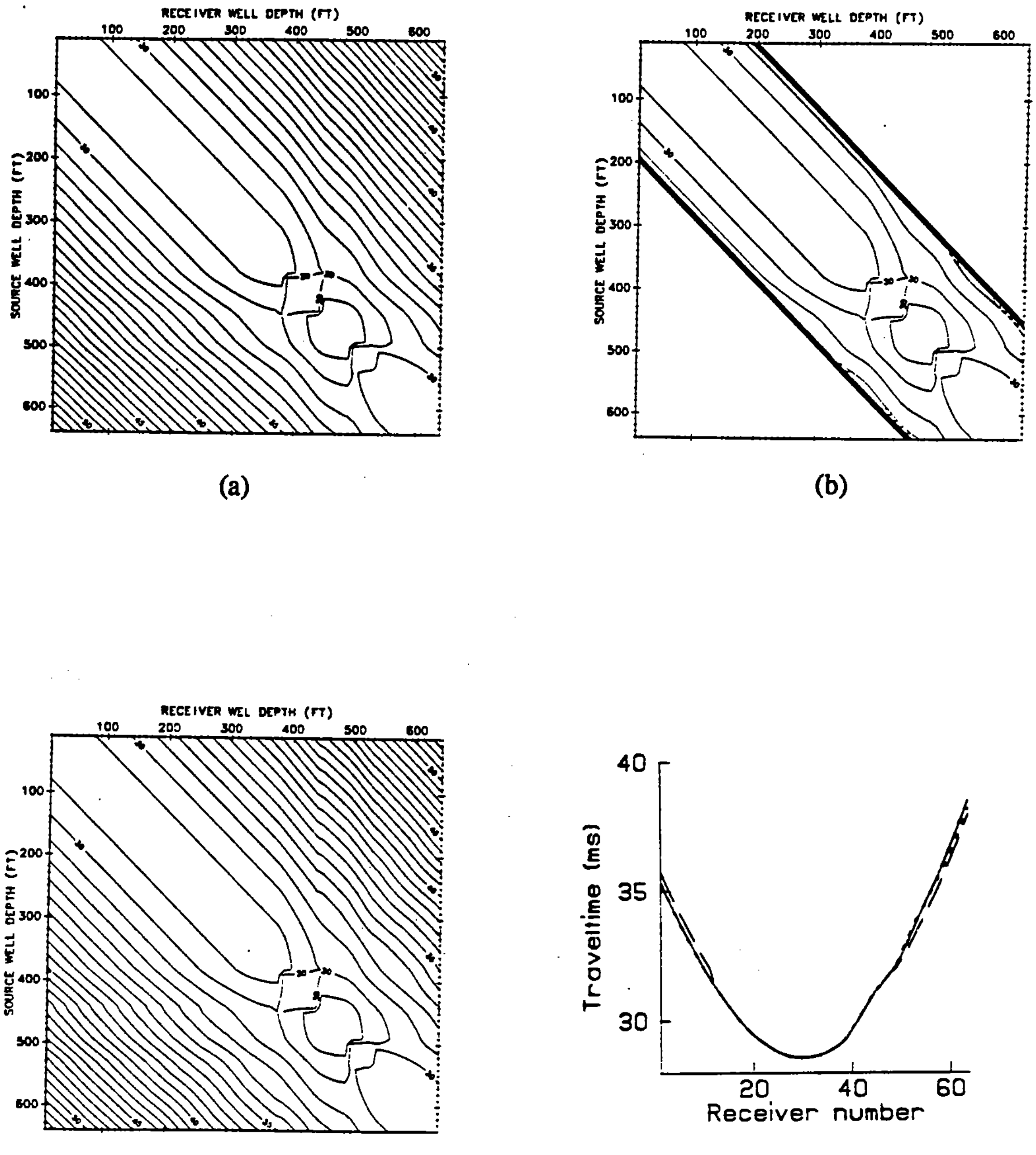

Fig. 3 (a) 1-D synthetic travel time picks; (b) truncation of the synthetic data; (c) restored large offset traveltime; and (d) comparison of the restorations via Radon transform and overall average.

CONCLUSIONS

The Radon transform provides a powerful and convenient way to represent and manipulate images, e.g., traveltime data fro arrays of sources and receivers. Far offset traveltimes can be recovered or restored by constructing traveltime hyperbolas in the transform domain. Results on synthetic and field data demonstrate that the approach is efficient and robust and that missing data can be estimated even when noise is present as in the case of the field data. The restored far offset data are important for reducing reconstruction artifacts in cross-well reconstructed images.

ACKNOWLEDGEMENTS

The authors thank the David and Lucille Packard Foundation for its financial support and the Gas Research Institute and Chevron Oil Field Research for their support in obtaining the field data set.

REFERENCES

A. K. Jain, Extrapolation algorithms for discrete signals with applications in spectral estimation, IEEE trans. Acous. speech sig. proc. ASSP-29, 1981

A. K. Jain, Fundamentals of digital Image processing, Prentice-Hall Inc. , 1989.

J. M. Harris, Simultaneous iterative transform tomography, STP report, Stanford, 1991.

R. W. Gerchberg, Super-resolution through energy reduction, Opt. Acta 14 No.9, 1979