Seismic Migration Interpolation using Time-Shift Imaging Condition

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Summary

This paper proposes a time-shift imaging condition as an interpolation tool which can be used to estimate the migrated image in between actual migration depth steps. The technique improves the computational efficiency for prestack wave-equation downward continuation shot migration without loosing significant accuracy.

Introduction

The zero time (lag) imaging condition has been commonly used in wave-equation migration in order to estimate a migrated image at a particular depth step (Claerbout, 1985). Recent variations, namely variable space and time lag imaging methods, have been used for depth-focusing analysis (DFA) for migration velocity analysis (MacKay and Abma, 1992) and for amplitude-versus-angle (AVA) analysis after angle transformation in wave-equation imaging (Sava and Fomel, 2006) respectively.

Here, a new, simple and fast application of the variable time-shift (or time lag) imaging condition is proposed to interpolate migration output between depth steps during the downward continuation process. For a typical production application, the downward continuation depth step size is set approximately equal to the depth sampling interval (5 m to 15 m) depending on the frequency and complexity of the data. In the interest of computational efficiency, it would be desirable to increase the migration depth step beyond the depth sampling interval and to rely on an interpolation scheme to fill in the migrated image at the missing depth steps. The speed increase is about equal to the ratio between depth step and depth sampling interval although an excessively coarse choice of depth step would not properly honor the integrity of the velocity variation unless certain correction measure is made (Mi and Margrave, 2001). Here, the interpolation is performed at the imaging condition stage rather than at the post-imaging stage; both results will be compared in this paper.

Methods

The imaging condition for wave-equation shot migration used in this paper is a scaled time cross-correlation (i.e. deconvolution) between the upward propagating receiver data wavefield and the downward propagating source wavefield (Kelly and Ren, 2003). Its frequency domain expression is

$$R(x,z_1,w) = U(x,z_1,w)\cdot D^*(x,z_1,w)/(D(x,z_1,w)\cdot D^*(x,z_1,w)+\varepsilon), \qquad (1)$$

where $R(x,z_1,w)$ is the imaged output at depth z_1 and space x; $U(x,z_1,w)$ is the receiver data wavefield extrapolated to that depth level, and $D(x,z_1,w)$ is the impulsive source wavefield extrapolated to the same depth level; * is the complex conjugate; and ε is a small stabilizing pre-whitening scalar. The standard approach is to compute the conventional zero time lag (τ =0) imaging condition by summing all the real parts of R along all frequencies w. In such case, there is no image output in between depth steps unless a post-image interpolation (i.e., up-sampling) is applied to the depth output. But in this paper, inverse temporal Fourier transforms are applied to equation (1) for every depth step in order to obtain the 'cross-correlated' wavefield $r(x,\tau(z))$ of all time lags:

$$r(x,\tau(z)) = \int_w R(x,z_1,w)e^{iw\tau(z)}dw\,. \qquad (2)$$

Then the output image at arbitrary depth z in the vicinity of z_1 is extracted from r between depth steps using the time lag of

$$\tau(z) = (z - z_1)/v(x,z), \qquad (3)$$

where v is the interval velocity. The choice of the time lag simulates different coincide times between the receiver and source wavefields at different depths. For $z = z_1$, equation (2) will degenerate to the conventional zero time lag imaging $r(x,\tau(z_1)=0) = r(x,z_1)$. The wavefield extrapolator can be of any types, and here a phase shift plus interpolation (PSPI) is used.

Data Examples

The objective of the example is to show how the quality of the impulse responses computed using the time-shift imaging condition interpolation method varies with respect to various depth steps (Δz = 10 m, 20 m, and 40 m, which are one time, two times and four times the depth sampling interval dz of 10 m respectively). The velocity used is 5000 m/s, and the CDP interval dx is 15 m.

Figure 1 shows the ideal reference impulse responses of the shot migration where no interpolation is needed (i.e., the migration depth step equals to the depth sampling interval, $\Delta z = dz =$ 10 m).

Figure 2 is the shot migration result using post-imaging linear interpolation (i.e., up-sampling) in the depth output. As migration depth increases, it degrades the impulse responses. The result in (a) with a depth step of 20 m (i.e., twice the depth sampling interval) shows a minor degradation and is quite comparable to figure 1. But the result in (b) with a depth step of 40 m (i.e., four times the depth sampling interval) is very degraded and not useful.

Figure 3 is the shot migration result using the new time-shift imaging condition as the interpolator. The result in (a) with a depth step of 20 m (i.e., twice the depth sampling interval) shows virtually no degradation when compared to the reference figure 1. Even in (b) with a depth step of 40 m (i.e., four times the depth sampling interval), where three interpolated images are output in between actual migration depth steps, the result is quite satisfactory showing only minor degradation. The run time is shortened by about four times compared to the reference test in figure 1.

Discussions

The proposed method produces better results in between depth steps compared to a simple linear interpolation on the post-imaged output. This is due to the fact that time-shift imaging takes advantage of wavefield propagation properties, but the post-image interpolation does not. Examples of Marmousi data will be given at the presentation date.

The speed increase of the proposed method compared to the actual migration of every single depth sample is increased by $\Delta z / dz$.

The position error compensation issue of using coarse migration depth steps in the case of heterogeneous media is beyond the scope of this paper but has been corrected by (Mi and Margrave, 2001).

Conclusions

A fast and simple interpolation method using a time-shift imaging condition is proposed to increase the speed of downward continuation shot migration. The speed increase is about equal to the ratio of migration depth step size and depth sampling interval.

References

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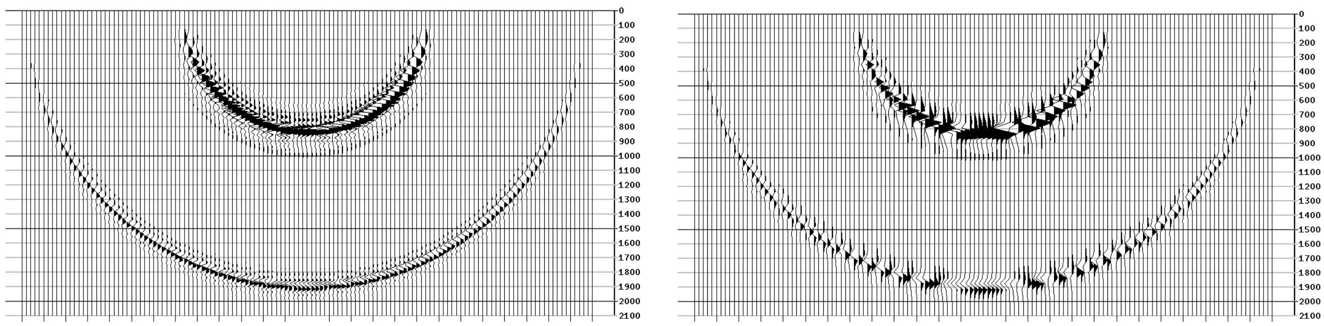
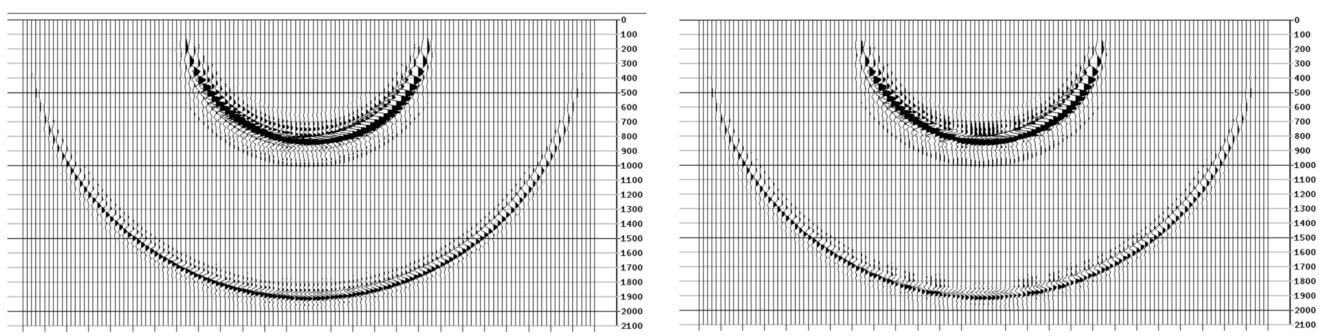
Figure 1. Reference shot migration results: the ideal impulse responses. No interpolation is needed as the depth step equals to the depth sampling interval ($\Delta z = 1dz =$ 10 m).



(a) $\Delta z = 2dz =$ 20 m (b) coarse $\Delta z = 4dz =$ 40 m

Figure 2. Shot migration results using post-imaging linear interpolation (i.e. up re-sampling). Results are degraded as depth step size increases.



(a) $\Delta z = 2dz =$ 20 m (b) coarse $\Delta z = 4dz =$ 40 m

Figure 3. Shot migration results using time-shift imaging condition as an interpolator. Results are not significantly degraded as depth step size increases.