Wave-equation MVA with extended CIPs
Tongning Yang and Paul Sava, Center for Wave Phenomena, Colorado School of Mines

Summary
Wave-equation migration velocity analysis (WEMVA) is an image-domain velocity model building technique using band-limited wave propagation and designed for complex subsurface areas. We propose a WEMVA approach with extended common-image-point gathers (CIPs) constructed sparsely along reflections and defined jointly for space- and time-lags. Using CIPs for WEMVA avoids the bias towards nearly-horizontal reflectors so that velocity information from steeply dipping events is well preserved. Also, the sparse sampling of CIPs reduces the cost for computation and storage of gathers. Furthermore, the flexible sampling of CIPs facilitates a target-oriented velocity optimization scheme. Synthetic examples demonstrate successful applications of this new approach.

Introduction
• In complex geologic regions, building an accurate velocity model is a challenging assignment.
• Wavefield-based velocity model building techniques are capable of rendering more accurate results because they can handle complicated wave propagation phenomena, i.e. multi-pathing, and sharp velocity contrast such as salt.
• Data-domain wavefield-based velocity model building method: Full Waveform Inversion (FWI).
• Image-domain wavefield-based velocity model building method: Wave-equation Migration Velocity Analysis (WEMVA).
• FWI updates the velocity model by minimizing the misfit between recorded and simulated data; WEMVA updates the velocity model by optimizing the coherence of migrated images.

WEMVA with different CIGs

Space-lag CIGs: $r(x, \lambda) = \int u_s(x-\lambda, t)u_r(x+\lambda, t)dt$  \hspace{1cm} (1)
• The objective of optimization is to focus reflections at zero lags.

Time-lag CIGs: $r(x, \tau) = \int u_s(x, t-\tau)u_r(x, t+\tau)dt$ \hspace{1cm} (2)
• The objective of optimization is to minimize focusing error of reflections.

Space-lag CIGs with correct and incorrect velocity models.

Time-lag CIGs with correct and incorrect velocity models.
Extended Common-image-point gathers (CIPs)

- Space- and time-lag extended CIPs
  \[ r(c, \lambda, \tau) = \int u_s(c-\lambda,t-\tau)u_r(c+\lambda,t+\tau)dt \]  

- CIPs are constructed on reflections only.
- CIPs are more robust for steeply dipping reflections.
- Given the correct velocity model, reflections focus at zero lags in CIPs. Otherwise, residual moveout is caused by the velocity model error.

CIPs with correct and incorrect velocity models.

Objective function

- The objective function can be formulated based on the semblance principle.
  \[ J(v) = \min \left| P[r(\lambda, \tau); v] \right|^2 \]  

- \( P \) is a penalty operator which annihilates the reflection when the velocity is correct and penalizes the feature caused by the velocity model error.
  \[ P[.] = |\lambda| \quad \text{or} \quad P[.] = \sqrt{\lambda^2 + (v \tau)^2} \]

- There are many possible choices for the penalty operator.
- An objective function based on the semblance principle has the property of convexity, which ensures a unique global minimum.

Penalty operators

Extended CIPs provide an alternative approach for implementing WEMVA. CIPs are computed sparsely on reflections using both the space- and time-lags in cross correlation. The objective function is designed using the semblance principle and constructed by applying the penalty operator to CIPs. Synthetic examples illustrate successful velocity optimization using WEMVA with CIPs. The examples also demonstrate the low computational feature and the target-oriented characteristic of CIPs, which are the main advantages of using such localized gathers.

Conclusions

References


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Box perturbation example

The first example consists of two horizontal layers with two box perturbations embedded. The velocity for the layers are 1.5 km/s and 1.6 km/s, respectively. The magnitude of the perturbations are -0.15 km/s and 0.15 km/s, respectively. The background model is constant with the velocity of the first layer.

The locations for CIPs are indicated by the red dots overlain on the migrated images.

The objective function is constructed using equation 4. The inversion is performed using a nonlinear conjugate gradient method. Here, only three iterations are enough to render a satisfactory updated model.

The quality of the image is improved after the inversion, especially the coherence of the bottom reflector.

The comparison between CIPs migrated with the background and updated model also implies the improvement of the image quality. Reflections are better focused in the CIPs with updated model. This confirms the success of the velocity optimization.
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Sigsbee 2A example

The second example is the velocity update for the subsalt portion of the Sigsbee 2A model. The velocity above the salt and salt geometry is assumed to be known. The background model in the target area is obtained by scaling the true model with a constant factor of 0.1.

The CIPs are sampled only on the bottom reflector to obtain a smooth update of the model. More CIPs can be sampled to increase the resolution of the result.

The process of the inversion is similar to the previous example. The updated velocity model is obtained after four nonlinear iterations.

The subsurface structure is better imaged with the updated model, as illustrated by the fact that the bottom reflector is correctly positioned, the fault is visible, and the diffractors are well-focused. The CIPs migrated with the updated model show better focusing of reflections.

Notice that residual moveout can still be observed in CIPs migrated with the updated model. Such a residual moveout is mainly caused by the uneven illumination in the subsalt area.