Pseudo-multiscale Waveform Inversion for Velocity Modeling

Dongwoo Yang[1] · Changsoo Shin[1] · Kwangjin Yoon[1] · Seungjin Yang[2]
Junghee Suh[1] · Soonduk Hong[1]

Abstract

We tried to obtain an initial velocity model for prestack depth migration via waveform inversion. For application of any field data we chose a smooth background layered velocity model ($v = v0 + k \times z$) as an initial velocity model. Newton type waveform inversion needs to invert huge Hessian matrix. In order to compute full Hessian matrix arising from full aperture data and full illumination zone, we meet insurmountable difficulties of paying astronomical computing cost. For the layered media, approximate Hessian emerging from single shot aperture data can be used repeatedly for split spread source configuration. In our work of using this Hessian characteristic of layered media we attempted to obtain the approximate velocity model as close as possible to the true velocity model in first iteration.

1. Introduction

A quality of subsurface image critically depends on how much the velocity model is close to a real velocity of the subsurface. The accurate depth migration image of seismic data requires correct velocity estimation tools. The traditional velocity modeling techniques are based on the Dix's equation derived from a layered media. Curvature and coherency inversion method choose the final velocity model by evaluating the depth image of prestack depth migration and by modifying velocity model iteratively (Landa et al., 1991; MacKay & Abma, 1993; Jhu et al., 1998). However, owing to the interpreter s intuition the most traditional velocity analysis tools have pitfalls of obtaining inaccurate velocity model. Unlike the existing velocity modeling tools, full waveform inversion is to search the final velocity model iteratively by minimizing the L2 norm between the measured data and the initial response. Many geophysists and applied mathematicians have attacked the waveform inversion for the last twenty years (Tarantola, 1984; Mora, 1987;, Shin, 1988; Pratt, 1999). In the waveform inversion, it is widely known that waveform inversion is robust in the low frequency band such that we avoid the local optima and obtain the low wavenumber velocity model. In order to do so Bunks et al., (1995) and Sirgue & Pratt (2001) applied the multigrid method, which uses inverted results at seismic low frequency band as an initial velocity model at high frequency band. Following similar approach to multigrid technique, we obtained each velocity model at several frequency band from low frequency to high frequency. Then we choose the final velocity model is close to the real velocity model by weighted summing perturbed velocity at several seismic frequency band.

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1) Seoul National University, Geophysical Prospecting Lab.(dwyang@gpl.snu.ac.kr)
2) HanYang University, Geophysical Prospecting Lab.

2. Methodology

It is widely known that full approximate Hessian in Gauss-Newton regularizes gradient vector ($J^T d$, where J is Jacobian and d is the residual seismogram). Because of astronomical computing cost to calculate the full approximate Hessian and to invert it, few people studied the property of Hessian (Pratt et al, 1998). To avoid construction of huge Hessian Shin et al., (2001) and Lambare et al., (1992) used diagonal element of Hessian to regularize the unscaled image ($J^T d$, migration image). To utilize full approximate Hessian and to overcome the cost of computing we choose the smooth layered background velocity model that does not need to construct full approximate Hessian for every source repeatedly. By exploiting source-receiver reciprocity of wave equation, we computed Jacobians, then used them for the computation of Hessian and gradient vector. Depth image can be defined as a zero lag cross-correlation of Jacobian and the residual seismogram, whereas Hessian can be defined as the zero lag cross-correlation of Jacobians themselves. Jacobian matrix in the low frequency band behaves like Rayleigh scattered wavefield radiate uniformly in all directions. In this study, to maximize the low frequency effect and to consider frequency contents of seismic data for inversion results, we applied pseudo-multiscale method at several frequency band from low frequency band to high frequency band. Then we calculated the final perturbed velocity ($\Delta p = (J^T J)^{-1} J^T d$) by summing weighted inverted velocities at each seismic frequency band. The resulting inverted velocity model is illustrated in Figure 1. The inverted velocity model is not the same but close to the true velocity model except salt bottom part. Figure 2 is the migrated image using the inverted velocity model by reverse-time migration.

3. Summary

In waveform inversion of using Gauss-Newton method it is nearly impossible to compute a full approximate Hessian for an arbitrary velocity model. To avoid the astronomical computing cost we chose smooth background layered velocity model as an initial velocity model. The full Hessian computed from the layered model can be used for every source repeatedly. We regularize gradient vector by using the full approximate Hessian and obtained close velocity model than the unregularized migration image. We expect that if we use the full Hessian calculate from a layered media, we will have a better defined initial velocity model for the prestack depth migration.

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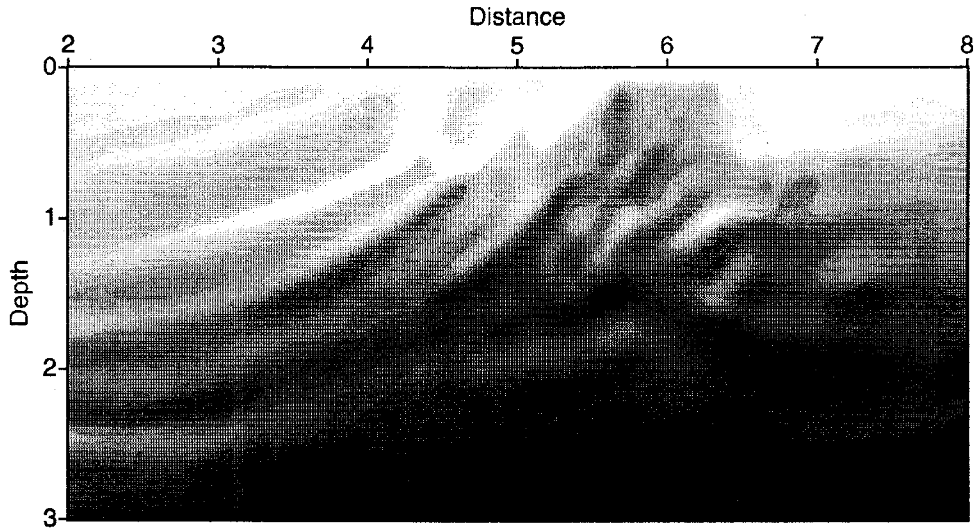

Figure 1 : Inverted velocity model of Marmousi model

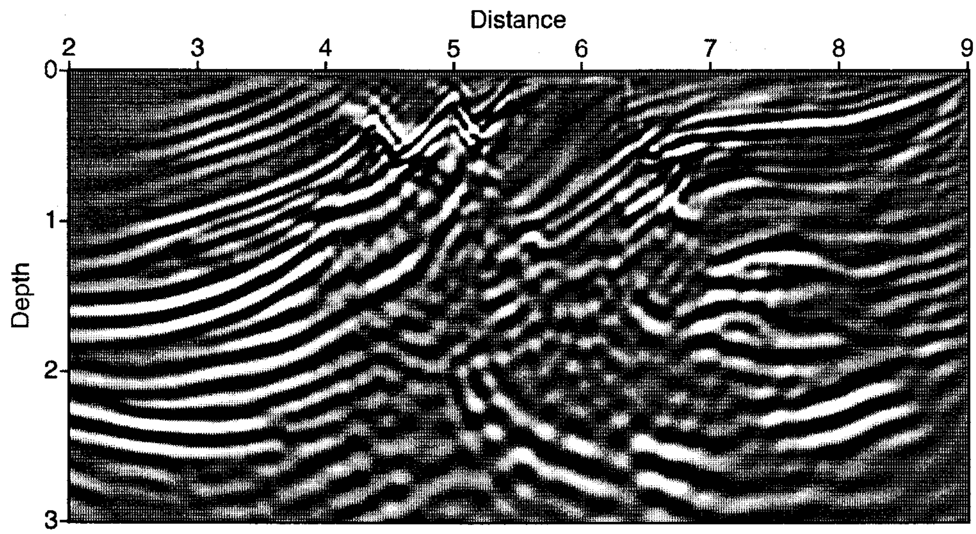

Figure 2 : Reverse-time migrated image of Marmousi model using inverted velocity