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Non-convex Seismic Acoustic Impedance Inversion

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SUMMARY

We present a new seismic acoustic impedance inversion method to improve the accuracy in the estimation of seismic impedances. In order to better recover the reflectivity amplitudes, we employ a non-convex deconvolution algorithm. In a simulated synthetic experiment, we compare the results of the proposed method with the methods, which use the most current deconvolution algorithms, i.e. the Weiner and sparse l1 deconvolutions. We show that the proposed method outperforms these custom methods to obtain acoustic impedances.

Introduction

The acoustic impedance Z , the product of medium density ρ and seismic wave velocity v , is the basic property which builds the foundation of the seismic reflection method. Basically, the relative differences in acoustic impedance time series leads to reflection train $r(t) = \frac{Z(t+1)-Z(t)}{Z(t+1)+Z(t)}$, which is unfolded as seismic traces, having the characteristic of blurring wavelet.

In an inverse manner, what we perform to obtain the acoustic impedance from seismic data is the application of a processing flow to produce migrated seismic sections, followed by implementing acoustic impedance inversion method. This is a tool to gain a quantitative rock-property describing an a reservoir from migrated seismic data. A critical step in impedance inversion is to remove the source signature from seismic traces to obtain reliable seismic reflectivity series, the so called deconvolution operation (Waters, 1978). The quality of employed deconvolution algorithm in recovery of the true reflection coefficients is very effective in properly obtaining the true seismic impedances. In this paper, we investigate an acoustic impedance inversion algorithm in which the deconvolution step is performed by a non-Convex programming (Gholami and Hosseini, 2012). Numerical synthetic simulations shows that the proposed algorithm is capable to bring more accurate results in comparison to ordinary methods, such as Weiner and even sparse l_1 deconvolution methods.

Method

The following explicit relation approximately links the acoustic impedances series, to the seismic reflection series

$$Z_{j+1} = Z_1 \exp(2 \sum_{k=1}^j r_k) \quad (1)$$

(Waters, 1978), for $|r_i| \ll 1$. To estimate reflectivity series from migrated seismic traces, a wide range of inversion based deconvolution algorithms has been introduced. Generally, the algorithms which assume a Gaussian distribution of added noise, includes minimization of the following cost function:

$$r = \arg \min_m \{ \|d - W * m\|_2^2 + \lambda \varphi(m) \}. \quad (2)$$

The regularization term, $\varphi(m)$, controls the behavior of obtained solutions. The most common term to use is l_2 and l_1 -norm of the model, which is known as Weiner and sparse deconvolution, respectively. Although, It has been shown that using the sparse deconvolution leads to sparse recovery of reflectivity series (which is more consistent to reality), (Taylor, 1979), it doesn't lead to the true estimation of reflectivity amplitude.

To combat the problem, here we employ the generalized potential function

$$\varphi_q^p(m) = \begin{cases} \frac{1}{q} (1 - (|m|^p + 1)^{-q}) & \text{if } q \neq 0 \\ \ln(|m|^p + 1) & \text{if } q = 0 \end{cases}, \quad (3)$$

Introduced by Gholami and Hosseini (2011), where the capaballity in more accurate estimation of reflector amplitude, while retaining the sparsity properties, is considered. The following example presents a typical acoustic impedance inversion by employing the proposed method.

Example

A synthetic model is generated for a geological model with 6 horizontal layers with constant density and velocity (the parameters for each layer is available in Table 1). The generated trace added with Gaussian noises (S/N= 10 db) is shown in Fig. 1 (a). To simulate blurring effects of the source, we convolve a Ricker wavelet having 20 Hz central frequency with the reflectivity.

Table1. Parameters of the used synthetic geologic model.

Layers	1	2	3	4	5	6
Velocity (km.s ⁻¹)	900	950	1100	1050	1200	1100
Density (kg.m ⁻³)	2000	2150	2250	2400	2300	2500
Thickness (m)	200	50	200	50	100	270

The reflectivity series obtained by Wiener deconvolution, l_1 -norm deconvolution and the proposed deconvolution are depicted in Figs.1 (b)-(d), respectively. The corresponding acoustic impedances evaluated by equation (2) are illustrated in Fig. 2. Obviously, the proposed non-Convex deconvolution outperformed two methods in estimating reflection series, and as a result the acoustic impedances are estimated more accurately, numerically and visually.

Figure 1 A synthetic trace (a) and recovered reflectivity series by Wiener deconvolution (b), l_1 deconvolution (c) and the proposed deconvolution (d). Red circles show the true reflectivities.

Figure 2 The true (blue) and estimated acoustic impedances obtained by Wiener (red), l_1 (black) and proposed (green) deconvolutions. To show the details a small part of the figure is zoomed in the right panel.

Conclusion

In this paper we employed a generalized non-Convex regularization term in deconvolution step of acoustic impedance inversion. We showed that our proposed method outperformed the classical methods.

References

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