

New Modified Band Limited Impedance (BLIMP) Inversion Method Using Envelope Attribute

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Abstract. Earth attenuates high frequencies from seismic wavelet. Low frequency seismics cannot be obtained by low quality geophone. The low frequencies (0-10 Hz) that are not present in seismic data are important to obtain a good result in acoustic impedance (AI) inversion. AI is important to determine reservoir quality by converting AI to reservoir properties like porosity, permeability and water saturation. The low frequencies can be supplied from impedance log (AI logs), velocity analysis, and from the combination of both data. In this study, we propose that the low frequencies could be obtained from the envelope seismic attribute. This new proposed method is essentially a modified BLIMP (Band Limited Impedance) inversion method, in which the AI logs for BLIMP substituted with the envelope attribute. In low frequency domain (0-10 Hz), the envelope attribute produces high amplitude. This low frequency from the envelope attribute is utilized to replace low frequency from AI logs in BLIMP. Linear trend in this method is acquired from the AI logs. In this study, the method is applied on synthetic seismograms created from impedance log from well 'X'. The mean squared error from the modified BLIMP inversion is 2-4% for each trace (variation in error is caused by different normalization constant), lower than the conventional BLIMP inversion which produces error of 8%. The new method is also applied on Marmousi2 dataset and show promising result. The modified BLIMP inversion result from Marmousi2 by using one log AI is better than the one produced from the conventional method.

1. Introduction

Information regarding Acoustic Impedance (AI) is essential for hydrocarbon reservoir characterization. Hydrocarbon reservoir is source of oil and gas which preserved in porous rock. Many inversion methods have been developed in recent years to obtain AI from seismic trace. One of the simplest and widely used inversion methods is the recursive inversion. In recursive inversion, the derived equation from the wave reflection is modified and the method principally inverts acoustic impedance in terms of reflectivity coefficient [1]. Acoustic impedance pseudologs have been developed by Laverne in 1975 [2]. In 1978, Waters developed inversion technique called SAIL (Seismic Approximate Impedance Log) [3], which derives impedance value from seismic data and low frequency information by stacking the velocities and well log. New impedance inversion scheme developed from SAIL called band limited impedance (BLIMP) was created by Ferguson and Margrave in 1996 [4], which used 2 Hz and 10 Hz (low frequency) data. BLIMP is a modification of SAIL, which also normalizes the

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spectra of computed impedance log from seismic trace, thus having the same range of value as the real impedance log. In 2014, Wu [5] proposed a method that generated acoustic impedance inversion technique using envelope attribute called Seismic Envelope Inversion (EI) [5]. The method combines full waveform inversion (FWI) technique and the envelope attribute. Envelope attribute contains ultra-low frequency (ULF). FWI technique requires ULF to recover the long wavelength of the background structure while the envelope attribute is used as smoothing background or initial model for FWI. Wu applied the envelope attribute as ULF due to the highly-cost use of low frequency source. The result shows that ULF from envelope attribute is suitable to be applied for initial model in FWI and furthermore, it yields a good result. In this study, new inversion technique is proposed by combining BLIMP and envelope attribute. The idea is basically to obtain low frequency data from an alternate source such as Envelope Inversion (EI) does. Thus, we use envelope attribute as ULF source for BLIMP. In order to assess the performance of the method, we apply the method on a case from a single well. A numerical test using Marmousi model was also performed in order to verify the accuracy of the proposed inversion technique. Marmousi model is a subsurface model that generated by a consortium which based on a geological model in North Quenguela Through in the Quanza Basin in Angola [6, 7].

2. Theory

2.1. Band Limited Impedance (BLIMP)

BLIMP method starts by computing impedance which is estimated from seismic traces. BLIMP uses equation (1) to invert seismic trace into impedance. Equation (1) is similar to the recursive inversion but with some modifications and assumptions.

$$I_{j+1} = I_1 \exp\left(\gamma \sum_{k=1}^j S_k\right). \quad (1)$$

Equation (1) integrates the seismic traces (S_k) and exponentiates the result to provide impedance traces. Variable γ is a scaling factor for the approximation in BLIMP. The equation is modified from Waters by including a scaling factor to estimate the impedance [3]. The SAIL method of Waters is summarized by Ferguson in the following procedure [4]:

- i. Obtain an impedance log,
- ii. Integrate then exponentiate each trace of seismic section,
- iii. Compute Fourier spectra of (i) and (ii),
- iv. Scale the spectra of impedance estimate from traces, so it matches with the values in impedance log range,
- v. High pass filter impedance log and add to the estimated impedance,
- vi. Inverse Fourier transform of (v).

Ferguson and Margrave [4] modified the procedure by removing linear trend of impedance log before the Fourier transform, and adding linear trend of impedance log after inverse Fourier transform. The new modified technique is called BLIMP and is currently used widely in seismic inversion.

2.2. Envelope Attribute

Envelope attribute contains ultra-low frequency information of a seismic trace [5]. Seismic trace can be expressed as an analytic signal with real and imaginary component. In seismic acquisition, we only record the real part ($r(t)$) which is a combination of envelope amplitude ($A(t)$) and phase ($\theta(t)$). The real part ($r(t)$) and the imaginary part ($q(t)$) of seismic trace are defined as:

$$r(t) = A(t) \cos \theta(t) \quad (2)$$

$$q(t) = A(t) \sin \theta(t) \quad (3)$$

and the envelope attribute ($A(t)$) can be expressed as:

$$A(t) = \sqrt{r(t)^2 + q(t)^2} . \quad (4)$$

Imaginary part of seismic trace can be obtained from the real part using Hilbert transform. The Hilbert transform trace operator ($f(t)$) can be written in equation (5) and the imaginary part is expressed in equation (6).

$$f(t) = r(t) + iq(t) \quad (5)$$

$$q(t) = \text{Im} [f(t)] . \quad (6)$$

3. Methodology

In this study, the inversion method is based on the idea of Envelope Inversion (EI) method. Low frequency signal from envelope attribute is able to recover the background structure. In this method, we propose to take account of low frequency from envelope attribute into BLIMP method. The following procedure describes the modified BLIMP method:

- a. Compute the Envelope Attribute from each seismic trace,
- b. Compute linear trend of (a) and subtract it,
- c. Compute linear trend of AI log,
- d. Compute the Fourier Spectra from (b),
- e. Determine the scalar value between (d) and seismic spectra (normalized) and apply to (d),
- f. Low pass filter (e) and add to seismic trace spectra,
- g. Inverse Fourier Transform of (f),
- h. Compute the Integrated Band Limited Impedance of seismic trace from equation (1), use I_1 only from one well and apply to all trace,
- i. Add linear trend (c) to (h).

Note that the AI log is used to obtain the linear trend. However, we replaced the AI log in low frequency domain with envelope.

4. Result and Discussion

4.1. Analysis of Envelope Attribute

Envelope attribute has high amplitude in low frequency domain. A simple analysis of envelope attribute in synthetic trace is demonstrated as follows:

Ricker wavelet with dominant frequency of 15 Hz is used to produce a synthetic trace by convolving it with synthetic reflectivity coefficient. The produced synthetic seismic trace is shown in Figure 1. The trace has negative amplitude while the envelope attribute trace as shown in Figure 2 does not have negative amplitude. The frequency domain of the synthetic seismic trace is shown in Figure 3. We can observe in Figure 3 that frequency domain of the seismic trace shows low amplitude of the low frequency signals. However, the frequency domain of the envelope attribute (Figure 4) shows very high amplitude of the signal with frequency in the range of 0-10 Hz. We can observe that the trace does not contain low frequency, on the other hand, the frequency domain of the envelope attribute shows large quantity of low frequency signal in the range of 0-10 Hz.

A better comparison can be seen in Figure 5 where the frequency domains of the two traces are plotted in the same axis. The dominant frequency of the wavelet is increased to 50 Hz in Figure 6 and we can observe a significant difference in the low frequency area. The difference in 0-15 Hz frequency domain clearly shows that envelope attribute could produce a high amplitude in low frequency and thus considered very suitable to be applied in the modified impedance inversion method.

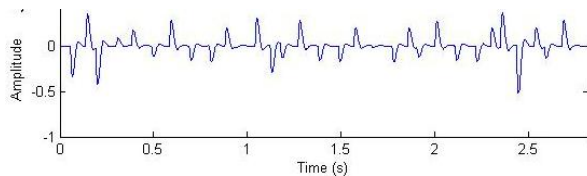


Figure 1. Synthetic trace with wavelet 15 Hz in time domain

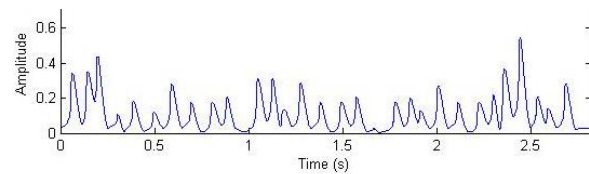


Figure 2. Envelope attribute from trace in time domain

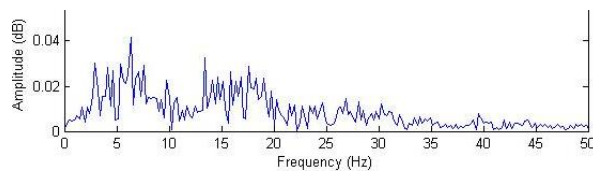


Figure 3. Synthetic trace with wavelet 15 Hz in frequency domain

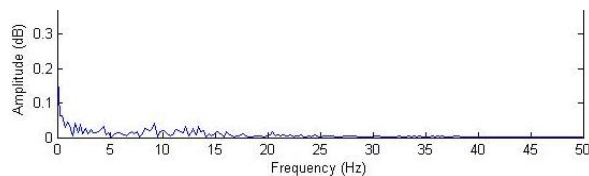


Figure 4. Envelope attribute from trace in frequency domain

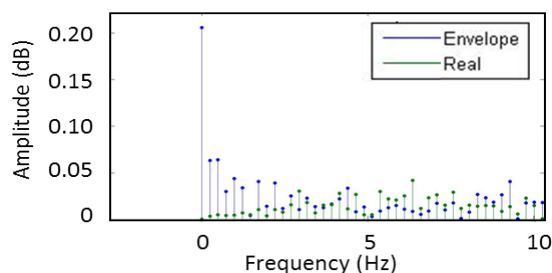


Figure 5. Envelope attribute (blue) show higher amplitude than seismic trace (green) with wavelet 15 Hz in low frequency domain.

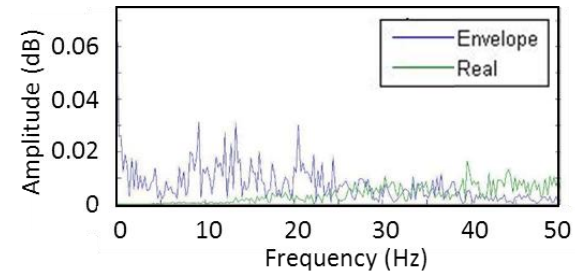


Figure 6. Envelope attribute (blue) show higher amplitude than seismic trace (green) with wavelet 50 Hz in low frequency domain.

4.2. Inversion test in field data

As an assessment of the proposed modified BLIMP method, we apply the procedure to a well log data from 'X' field. We compare the results from different AI inversion techniques, i.e., the recursive inversion, BLIMP, and the modified BLIMP. In Figure 7, the result from the three methods are compared. Recursive inversion, BLIMP and modified BLIMP has misfit value of 11.82 %, 8.1250% and 3.4% respectively. The proposed modified BLIMP has the smallest misfit value. We also found that the misfit percentage is good if the frequency cut off for envelope is in the range of 6-9 Hz as shown in Figure 8.

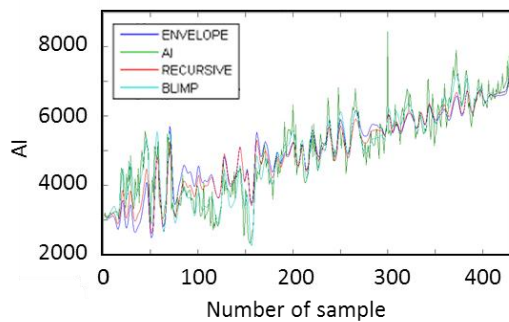


Figure 7. Inversion using modified BLIMP (blue), recursive plus AI log trend (red) and data log (green).

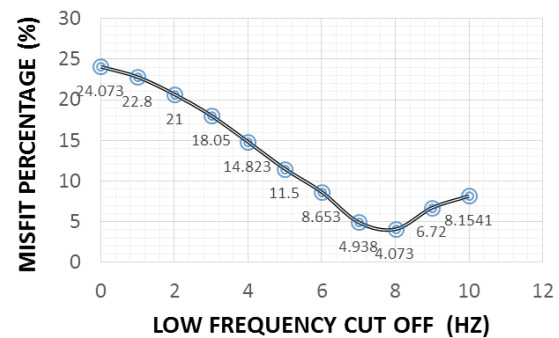


Figure 8. Misfit percentage in different low frequency cut off

4.3. Inversion test using Marmousi2

Marmousi model is a complex synthetic 2D acoustic data set which generated from the estimation based on a real situation. It contains many reflectors, steep dips and strong velocity gradients. Marmousi model was generated based on the North Quenguela Trough in Angola [6]. Original Marmousi model only provides the propagation of compressional waves. Marmousi2 model is a modified Marmousi model which supports not only compressional waves, but also shear waves, converted waves, and all kind of guided waves including those traveling along the sea floor [7]. The structure of Marmousi2 model is shown in Figure 9.

Inversion result of the Marmousi can be seen in Figure 9-12 where the color indicates the value of the relative acoustic impedance (AI), the horizontal axis is offset line and the vertical axis is depth. In Figure 9 we clearly see the detailed structure of Marmousi model from the acoustic impedance. In Figure 10, the recursive inversion expose structure contrasts such as fault and dip, however it cannot reveal any background structure color (which reflects the lithology). BLIMP method in Figure 11 shows background structure (colored) and thus we can determine the lithology. Although the result shows similar gradation of general structure, it fails to display the detailed structure. The Modified BLIMP inversion in Figure 12 produces adequate and even good detailed structure background compared to true Marmousi2 model in Figure 9. In Figure 12, the result from the modified BLIMP reveals structure contrast as well as the background structure (colored) that agrees satisfactory with the structure contrast. Compared to other inversion methods, modified BLIMP produces the best result.

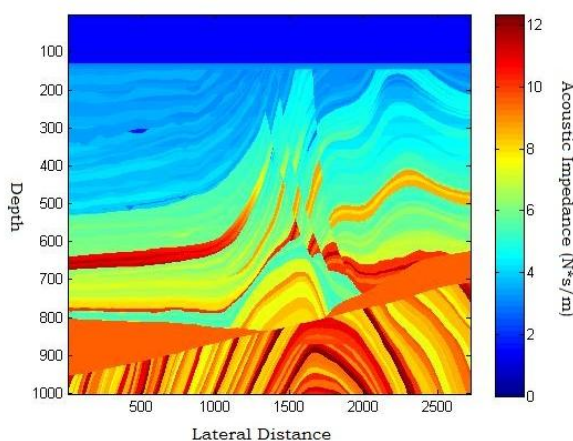


Figure 9. True Marmousi model (Color key in $\text{Kg}\cdot\text{m}/\text{s}^2$)

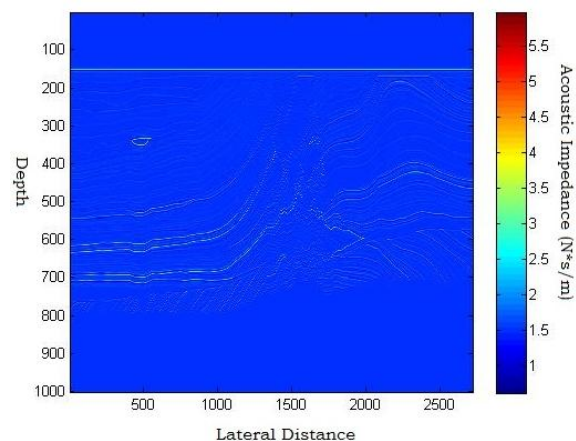


Figure 10. Inversion test using recursive inversion (Color key in $\text{Kg}\cdot\text{m}/\text{s}^2$)

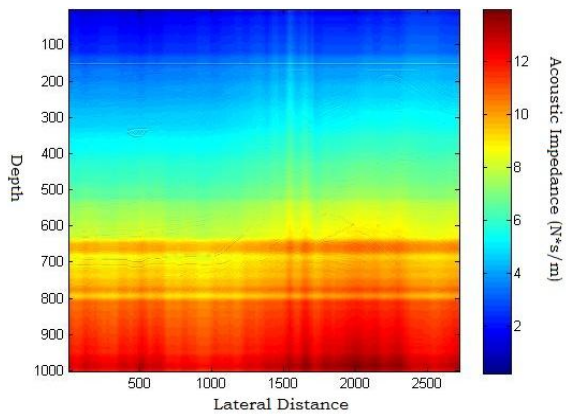


Figure 11. Inversion test using BLIMP (Color key in $\text{Kg}\cdot\text{m/s}^2$)

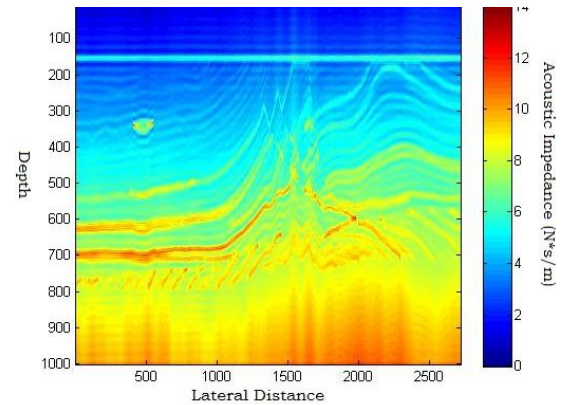


Figure 12. Inversion test using modified BLIMP (Color key in $\text{Kg}\cdot\text{m/s}^2$)

Note that the comparison of true model and modified BLIMP inversion result (black circle) fails to identify the gas area. The detailed acoustic impedance in gas area is shown in Figure 13. The envelope attribute contributes to this error due to the nature of its equation (squared, thus impossible to reveal either negative impedance contrast, or positive impedance contrast).

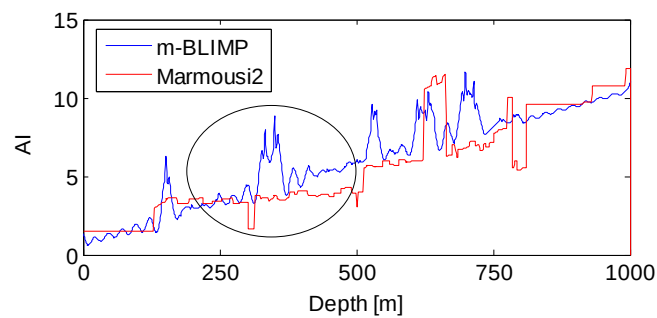


Figure 13. Acoustic impedance in gas saturated area for True Marmousi

5. Conclusion

The test from a well log data shows promising results which describe the capability of the proposed new modified BLIMP to produce more accurate AI inversion. The Modified BLIMP has better misfit than the recursive or the conventional BLIMP and has small misfit when applied to the 6-9 Hz cut off frequency. The modified BLIMP also yields the best result for Marmousi2 data, compared to recursive inversion and BLIMP. There is still a drawback of this method however, that the modified BLIMP cannot show the gas saturated area. One factor that distinguishes the modified BLIMP from other methods is that the modified BLIMP inversion can be carried out without having to build the velocity model or horizon picking, which is clearly very useful and potential in reducing cost of inversion.

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