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Application of Adaptive Predictive Deconvolution in Marine Seismic Data

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Abstract

Aiming at reverberation and interlayer multiple short period common multiples, with predictive deconvolution multiple attenuation methods exist this problem several residues, through the design of adaptive filter, iterative formula of least mean square algorithm to update the adaptive predictor of key parameters of deconvolution, predictive step and factor by multiple wave length distribution period and different to automatically set the range. Through the model experiment, the method of reverberation, interlayer multiples were especially obvious effect data, and verified by practical data analysis maps, some key results contrast income, show that the method has a good application prospect.

Keywords: *interlayer multiple, attenuation multiple, adaptive predictive deconvolution*

1. Introduction

The formation of the marine multiple waves is related to marine acquisition environment. Since the excitation and receiving are both in the seawater under the surface, while sea and air, hard sea bottom and seawater are good reflection interface, and seawater has very small attenuation on acoustic waves, so it forms multiple wave which bounces back and forth between the sea surface and the seabed; In addition, because the marine subsurface medium is better at layering, if it makes better compaction, it will form stronger reflective interface and multiple waves which reflect back and forth between the strata [1].

The multiple waves of marine seismic data includes two categories which are submarine whole multiple waves and interlayer multiple waves. The method of multiple waves suppression is mainly to conduct multiple waves suppression based on apparent velocity differences in multiple waves and one wave, frequency differences, differences in occurrence and the cyclical nature of multiple waves.Interlayer multiple waves, reverberation and others are common multiple waves on the sea. It is difficult to obtain a better suppression effect by using two-dimensional filtering waves such as cohere, fkfilt, τ-p transform and beamforming (bfm) and other methods [2]. This article describes an adaptive predictive deconvolution technique to attenuate this type of multiple waves, by comparison with the result of conventional attenuation interlayer multiple wave attenuation method, which indicates that the method has a good treatment effect [3].

2. Theory and Methods

When the seabed is shallow, multiple waves of seabed short cycle is often mixed with the one wave and it is difficult to distinguish. It can accurately identify multiple waves by correlation analysis in accordance with its cyclical type. Then it uses predictive deconvolution method to make multiple waves attenuation. For multiple waves produced by complex structures, because it does not fully comply with the periodic, the adaptive predictive deconvolution technology can be used. It conducts attenuation through a range of adjustment. The adaptive method is more effective than standard predictive deconvolution. The predictive deconvolution method assumes that the reflection series is uncorrelated white noise sequence. It is mix of non-periodic and unpredictable type. Multiple waves has periodic property and it can be predicted. It can predict the multiple waves by correlation function from the initial reached

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reflection sequence, and then predict pure interference part from the information of one reflection and multiple interference from the seismic records, then minus the part of pure interference [4, 5]. However, in practical applications, only the normal incidence, now zero offset record can better maintain periodicity of multiple waves. For this situation, the paper introduces time-varying forecast step and factor length to conduct multiple wave attenuation of complex structure [6].

2.1. Prediction Deconvolution Principle

In the seismic data processing of seismic data, predictive deconvolution is generalized least-squares deconvolution method. It is mainly used to suppress multiple waves, sea reverberation and other normal interference wave. The key question is to determine the optimal predictor and make the energy error between the forecast and actual value is minimum.

Let c(t) as predictor, x(t) is earthquake input signal ,the predictive value of a future moment t+a:

$$\hat{x}(t+\alpha) = c(t) * x(t) = \sum_{\tau=0}^{m} c(\tau) x(t-\tau)$$

The error with actual future value $x(t+\alpha)$:

$$\varepsilon(t+\alpha) = x(t+\alpha) - \hat{x}(t+\alpha)$$

By least-squares principle, even if:

$$\begin{aligned} Q &= \sum_{t=0}^{T} [x(t+\alpha) - \hat{x}(t+\alpha)]^2 \\ &= \sum_{t=0}^{T} \left[x(t+\alpha) - \sum_{\tau=0}^{m} c(\tau) x(t-\tau) \right]^2 \to \min \end{aligned}$$

Get:

$$\frac{\partial Q}{\partial c(s)} = 0 \qquad (s = 0,1,2,\cdots,m)$$

In accordance with the principle of minimum deconvolution, the above formulas can derive for T-P Leeds matrix equation:

$$\begin{bmatrix} \varphi_{xx}(0) & \varphi_{xx}(1) & \cdots & \varphi_{xx}(m) \\ \varphi_{xx}(1) & \varphi_{xx}(0) & \cdots & \varphi_{xx}(m-1) \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{xx}(m) & \varphi_{xx}(m-1) & \cdots & \varphi_{xx}(0) \end{bmatrix} \begin{bmatrix} c(0) \\ c(1) \\ \vdots \\ c(m) \end{bmatrix} = \begin{bmatrix} \varphi_{xx}(\alpha) \\ \varphi_{xx}(\alpha+1) \\ \vdots \\ \varphi_{xx}(\alpha+m) \end{bmatrix}$$

In the equation, the coefficient matrix on the left is the autocorrelation of seismic wavelet $\varphi_{bb}(\tau)$, the column matrix on the right is the cross-correlation of desired output with wavelet $\varphi_{db}(\tau)$. The predictive filter factor *c (t)* can be obtained when this equation is solved, then use *c (t)* to filter the input *x (t)* predictive to get the predictive value of the future time:

$$\hat{x}(t+\alpha) = \sum_{\tau=0}^{m} c(\tau) x(t-\tau)$$

It uses past value and present value of given x (t) , to get the predictive value of $t+\sim$ in future time by predictive filter, which $\sim$ is called the prediction step.

2.2. Prediction Deconvolution Principle

It will cause errors when using the above theoretical approaches in the actual seismic data processing mainly because: 1) Reflection coefficient is not a white noise, the errors will exist when the autocorrelation of the seismic records instead of wavelet autocorrelation is regarded as the coefficient matrix of deconvolution equation; 2) The seismic wavelet is not minimum phase, even if seismic wavelet of shothole seismic records is not the ture minimum phase wavelet. Therefore, the error exists in the application of minimum-phase wavelet deconvolution equation. 3) There is variety of coherent interference and random noise in noise actual seismic records and there are errors with noise-free assumption of the deconvolution.

For predictive deconvolution, the exist of multiple reflections in irregular layers and noise interference will make it difficult to determine the length of the predictor and the prediction step. While adaptive deconvolution based on adaptive linear filtering techniques, the key prediction operator is calculated by designing for each sampling point with an adaptive algorithm. So it can effectively filter out time-varying multiple reflection interference and interlayer multiple wave to achieve the purpose for the seismic data “discriminating” to meet the requirements of the structural interpretation.

Assume that signal column vector X_k is combined by elements $x_{k0,}x_{kl},\ldots x_{kl}$, while the corresponding automatic adjusted weight column vector F_k is combined by the elements $f_{k0},f_{k1},\ldots f_{kl}$.The output signal is:

$$\hat{y}_k = \sum_{l=1}^{L} f_{kl} x_{kl} = F_k^t X_k = X_k^t F_k$$

Assume another group of desired output signal y_k, it automatically adjusts the weighting coefficient by adaptive filter, the difference of energy of the difference between y_k and $\hat{y}_k$ achieve the minimum in accordance with an algorithm criteria, i.e.:

$$\varepsilon k = yk - \hat{y}k = yk - F_k^t X_k = \varepsilon \min$$

This method that makes automatic control of the energy errors output weight vector εk to achieve minimum is adaptive technology. Adaptive deconvolution is deconvolution operator designed based on time shift of time window analysis of seismic records in the single-aisle of the prestack of CMP gathers, it can be understood as the commonly used predictive deconvolution extension into a single-aisle allowing the operator to do adaptive adjustment [7-9].

Adaptive filter is designed as follows in this paper:

$$F(i,t) = A(i) + B(i) * \cos(kt) + C(i) * \cos(2kt)$$

In In the above formula, C(i) represents the adaptive filter; t is the sliding time window; k is the length of the analysis time window; When B(i) and C(i) tends to zero, the calculation process is the standard predictive deconvolution; A, B, C can be calculated by the least squares approximation.

The process is as follows:

(1) It uses the analysis time window to predict and minus multiple wave energy from the seismic trace and outputs intermediate result one, the process is as good as the general deconvolution;

(2) It uses cos (kt) of the filter to form envelope gather I;

(3) It uses envelope gather I to forecast and lose more multiple wave energy in the intermediate result I and outputs the intermediate result II;

(4) It uses cos(2kt) of the filter to form the envelope gather II;

(5) It uses the envelope gather II to predict and lose more multiple wave energy from the intermediate result II;

(6) Output result.
The corresponding algorithm is as follows:
(1) The predictive value is made by the initial predictor

$$\hat{x}(t+r)=\sum_{l=0}^{L} f(l)x(t-l)=F^{T}(t)X(t)$$

In the above equation, the predicted step is r.
(2) Find the difference of actual input value and predicted value

$$\varepsilon(t+r)=x(t+r)-\hat{x}(t+r)$$

(3) It uses the iterative formula of the least mean square algorithm to update the predictor of adaptive predictive deconvolution

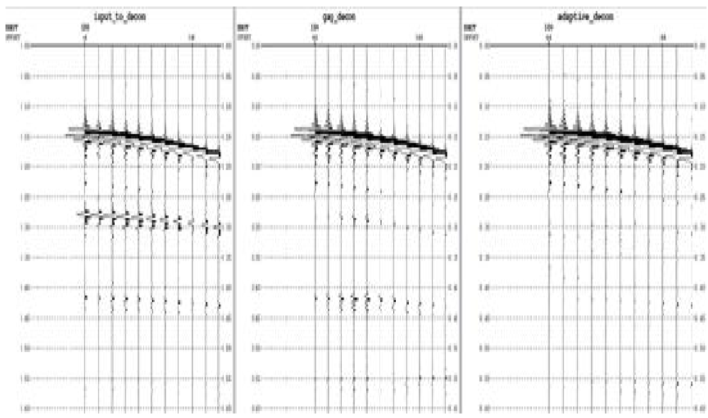
$$F(t+l)=F(t)+2\phi\varepsilon(t+r)X(t)$$

In the above equation, the length of predicted factor is l, the iterative step is ϕ.

In the process, it is different that every prediction step, the factor of length and time windows adopted in the horizontal for adaptive deconvolution, while for the prediction deconvolution, the time window can change, but predicted step and factor length are fixed. It is essentially different among them.

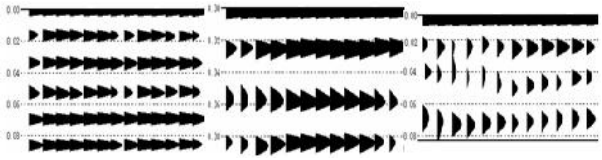
3. Model Simulation

Figure 1 and Figure 2 are the comparison figures of adaptive predictive deconvolution model before and after experiment. Figure 1(a) is primitive shot gather forward model of submarine twice and third multiple waves of back and forth between the seabed and the sea level. If the autocorrelation is good (Figure 2(a)), it indicates multiple wave development; Figure 1(b) is model predictive deconvolution result. The autocorrelation is not obvious (Figure 2(b)), and there still exists more residues on two and three multiple waves related to seabed; Figure 1(c) is the results using by adaptive deconvolution .The autocorrelation is not obvious, multiple waves similar phase axis is disrupted (Figure 2(c)), and two and three multiple waves is suppressed clean very much. It can be found that the effect of adaptive deconvolution attenuation multiple wave is better than the predictive deconvolution method from Figure 1 and Figure 2. That is, the theory of adaptive deconvolution is more advanced than predictive deconvolution.



(a) (b) (c)

Figure 1. Comparison Chart of Model Single-shot Record Adaptive Deconvolution Results. (a) Original single shot model, (b) predictive deconvolution model, (c) adaptive predictive deconvolution model

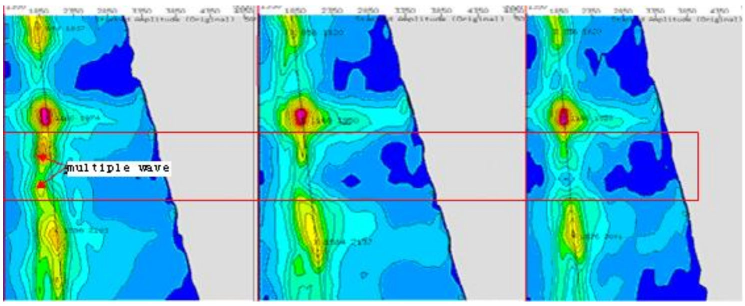


(a) (b) (c)

Figure 2. Comparison Chart of Model Single-shot Record Adaptive Deconvolution Results; (a) Original single-shot model autocorrelation, (b) predictive deconvolution model autocorrelation, (c) adaptive predictive deconvolution model autocorrelation

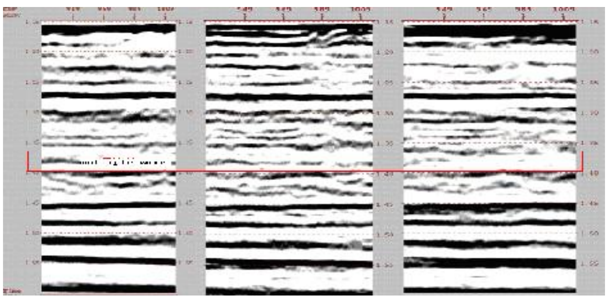
4. Example of the Actual Data Processing

Actual data selected by this method are mostly multiple waves which is representative of the 00Z measured line in East China Sea. It can be seen from the figure, significant wave is followed by two multiple waves, the energy of multiple wave is strong. Figure 3 and Figure 4 are comparison charts on the results of the two methods from the velocity spectrum, gather and stack section. The results show that in the implementation of the two methods, the first multiple wave is not repressed completely but from the view point of gather, the effect of adaptive deconvolution repression on first multiple wave is better than predicted deconvolution. In other words, on the stacked section, adaptive deconvolution results of a first multiple wave phase axis energy is worse than the predictive deconvolution but you can not see it by the naked eye. Analyze the second multiple wave, it can be found that, the effect of adaptive deconvolution repression is obviously superior to the predictive deconvolution repression. It compares the results of the two methods from the overall effect on the profile in Figure 4. The results show that the adaptive deconvolution results maintain the better effect than the wave group characteristics of predictive deconvolution results.



(a) (b) (c)

Figure 3. Comparison Chart of Velocity Spectra Deconvolution Results; (a) velocity spectra before deconvolution, (b) velocity spectrum after predictive deconvolution, (c) velocity spectra after adaptive predictive deconvolution



(a) (b) (c)

Figure 4. Stack Section Comparison Chart of Deconvolution; (a) Stack section before deconvolution; (b) stack section after prediction deconvolution; (c) stack section after adaptive predictive deconvolution

5. Conclusion

According to the theoretical model and the actual data processing results, on the whole, in the range of depth of 500m of the seismic data collected in shallow water, the interlayer multiple wave is in development, in the case that the cycle of near way and farther way is inconsistent and time difference is relatively small, the effect of the adaptive deconvolution approach is better than in the suppression of multiple wave and improvement of the characteristics of the wave group for predictive deconvolution approach [10]. But the existing adaptive deconvolution procedure itself does not have the time shift function for target processing. In the selection of time window, it only designs for the purpose layer. It has played a certain role in bondage on repression for multiple wave. It will cause that the effect is not obvious on some actual data processing and sometimes even worse than the effect of predictive deconvolution. In addition, due to the different theoretical basis, the machine-hour occupied in practical work by this method is more than approximately 5.45 times of normal predictive deconvolution method.

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References

[1] Xiao EI, Chen Y, Wan HA. *Surface-related multiple elimination on marine seismic data.* Progress In Geophysics. 2010; 25(3): 1057-1064.
[2] Zhang JH, Liao YH, Zheng XJ. Discuss of several theoretical questions using predictive deconvolution to remove multipule. *Petroleum Geophysics.* 2006; 28(4): 15-19.
[3] Li ZY, Jiang H, Li DS. Discussion on marine seismic data processing technique. Oil Geophysical Prospecting. 2007; 42(S1): 8-13.
[4] Porsani M, Ursin B, Silva M. Dynamic estimation of reflectivity by minimum-delay seismic trace decomposition. *Geophysics.* 2013; 78(3): 109-117.
[5] Ventosa S, Le RS, Huard I, Pica A, Rabeson H, Ricarte P, Duval L. Adaptive multiple subtraction with wavelet-based complex unary Wiener filters. *Geophysics*. 2012; 77(6): 183-192.
[6] Liu ZP, Wei Z, Zhu ZY. *Multiple attenuation using multichannel predictive deconvolution in radial domain*. SEG Technical Program Expanded Abstracts 2012, Society of Exploration Geophysicists, 2012: 1-5.
[7] Li ZX, Lu WK. *Hybrid Demultiple Method in the Radon Domain.* 75th EAGE Conference & Exhibition incorporating SPE EUROPEC. 2013.
[8] Wang B, Li N, Ye Q. *Multichannel Predictive Deconvolution Method in Acoustic Reflection Well Logging*. 75th EAGE Conference & Exhibition incorporating SPE EUROPEC. 2013.
[9] Vershinina AV, Muzichenko EL, Kurin EA, Denisov MS. Eliminating Multiples from Ocean Bottom Seismic Data. Seismic Technology. 2012; 9(3): 1-11.
[10] Nongpiur R, Hetherington PA. U.S. Patent No. 8,150,682", Washington, DC: U.S. Patent and Trademark Office. 2012.