High-amplitude Noise Attenuation
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Summary
In this paper, two techniques of attenuating swell noise, seismic interference and ground roll are discussed. Based on the characteristic of the noise, using a projection filter or jointly using a prediction filter and a pattern-based adaptive subtraction technique has proved to be particularly effective when attenuating these high-amplitude noises. Real data applications show encouraging results.

Introduction
Attenuating the high-amplitude noises, such as swell noise, seismic interference, ground roll and multiplcs, is really a big challenge in the seismic data processing. The final subsurface image may provide wrong information for the interpretation without attenuating these high-amplitude noises. Regarding the multiple attenuation, different techniques have been discussed in many literatures (Berkhout, 1982; Verschuur et al, 1992; Guo, 2003). We wouldn’t discuss them in paper. The emphasis here is how to attenuate the swell noises, seismic interference noises and ground roll.

According to the characteristic of the high-amplitude noises, these high-amplitude noises can be divided into non-coherent high-amplitude noises, such as swell noises, highly dispersed ground roll, etc., and coherent high-amplitude noises, such as seismic interferences, ground-roll, etc.

Conventional way of attenuating the non-coherent high-amplitude noises is first to detect these high-amplitude noises, and to scale down or mute them. In this way, the noises are attenuated; however, unfortunately the signals are attenuated as well. Of course this is not what we expected.

Conventional way of attenuating the coherent high-amplitude noises is to apply a F-K filter or a $\tau - p$ filter to the data within a given range. The drawback with these algorithms is that these filters are deterministic, which introduces some limitations when signals and noises have overlaps in F-K or $\tau - p$ domain.

How to attenuate these kinds of noises has been a critical issue in the seismic data processing. An algorithm was introduced to attenuate high-amplitude noises by using a prediction filter to recover the frequency components contaminated by the high-amplitude noises(Guo,1993), and later another similar algorithm was introduced by using a projection filter(Soubaras,1995). In order to attenuate the non-coherent high-amplitude noises, we use a strategy that first detects the frequency components that are contaminated by the high-amplitude noises, and then these frequency components are replaced by filling in based on the frequency components of the neighbor traces using a projection filter. Using the strategy that first predicts the noises and then subtracts them from the input data can attenuate coherent high-amplitude noises. We use LSQR to automatically estimate the coherent high-amplitude noises, and then adaptively subtract them from the input data based on a pattern-based algorithm (Guo, 2003).

Production implementations of these techniques show encouraging results.

Methodology
High-amplitude noises include non-coherent high-amplitude noises and high-amplitude coherent noises. We use different strategies to attenuate them.

- Non-coherent high-amplitude noise attenuation
In the marine environments, swell noise is one of the non-coherent high-amplitude noises. It is one of the key problems needed to solve. Sometimes the swell noise is so strong that we couldn’t identify the signals from the data. How to attenuate the swell noise has been one of our key efforts.

The frequency content of swell noise usually falls in the low frequency band. Abnormal frequency component, which is contaminated by the swell noises, can be detected within this low frequency band when the residual of a prediction error filter(PEF) exceeds a threshold, also the abnormal frequency component can be identified by comparing its amplitude with those of the neighbor traces. If its amplitude is greater than a threshold defined by the median value of the neighbor traces, it will be considered to be the abnormal value and should be replaced by a better frequency component. This better frequency component is obtained by filling in based on the frequency components of the neighbor traces using a projection filter. The relation between the projection filter and the PEF can be formulated as

$$P = A^T \left( AA^T + \varepsilon^2 I \right)^{-1} A$$  \(1\)

where $P$ is the matrix of the projection filters, $A$ is the matrix of the PEFs, $\varepsilon$ is a pre-whitening constant, $T$ denotes the conjugate transpose.
Coherent high-amplitude noise attenuation

As described previously, coherent high-amplitude noises, such as seismic interferences, can be attenuated by the strategy that first estimates the noises and then adaptively subtracts them from the data.

Local linear events in f-x domain are spatially predictable. In most cases, coherent high-amplitude noises are locally linear, so this kind of noises is locally predictable. The strong coherent events can be estimated based a prediction error filter, which contains the information of the high-amplitude coherent noises. Based on these filters, the high-amplitude coherent noises can be obtained. These estimated high-amplitude coherent noises usually don’t exactly match the real noises in the data, so next step is to adaptively subtract these events from the input data by using a matching filter.

Unfortunately, when signals strongly interfere with coherent noises, conventional adaptive subtraction algorithms give biased signals after adaptive subtraction. In order to solve the problem, a pattern-based algorithm is presented (Guo, 2003). We use this algorithm to subtract the coherent high-amplitude noises from the data. It can be formulated as

\[ A_p B_p (Nf - D) \approx 0 \]  

(2)

\[ \hat{f} = (N^T B_p^T A_p^T A_p B_p N)^{-1} N^T B_p^T A_p^T A_p B_p D \]  

(3)

where \( D \) is the matrix of input data, \( N \) is the matrix of the estimated coherent high-amplitude noises. \( f \) is the matrix of matching filters, \( \hat{f} \) is the LSQR solution, \( A_p \) is the matrix of signal PEFs, \( B_p \) is the matrix of projection signal filters,

\[ B_p = \varepsilon I (A_p A_p^T + \varepsilon I)^{-1} \]  

(4)

where \( \varepsilon \) is a pre-whitening constant, \( T \) denotes the conjugate transpose.

Examples

The application of these algorithms to both marine and land datasets shows encouraging results. Fig. 1 shows selected common shot gathers with non-coherent high-amplitude swell noises. Fig. 2 shows the result of swell noises attenuation (The name of the code is FXEDIT). From Fig. 2 we can see the swell noises have been successfully eliminated. Fig. 3 shows the difference between Fig. 1 and Fig. 2. We can see that most of the swell noises have been removed. Fig. 4 shows two shot gathers before noise attenuation. They are from a land dataset with strong ground roll and high frequency air blasts. Some parts of the noises are coherent, and some parts of them are highly dispersive. These kinds of noises can be considered as non-coherent high-amplitude noises, and can be attenuated by using its corresponding algorithm described in this paper. Fig. 5 shows the result after noise attenuation. We can easily see that the strong noises have been removed. Fig. 6 shows some selected CMP gathers before noise attenuation. Fig. 7 shows the result after noises attenuation. The noises with low velocities and high frequency components are successfully attenuated. The result is again very satisfactory. Fig. 8 shows the difference between Fig. 6 and Fig. 7. Fig. 9 shows a stacked section before high-amplitude noise attenuation. Fig. 10 shows the result after high-amplitude noise attenuation. We can see that after noise attenuation, the S/N ratio is greatly improved. Fig. 11 shows the difference between Fig. 9 and Fig. 10. It indicates that the noises have been successfully removed. Fig. 12 shows a shot gather with seismic interferences. Fig. 13 is the result after seismic interference attenuation (the name of the code is DESI). We can easily see that the most of the seismic interferences have been removed. Fig. 14 shows the difference between Fig. 12 and Fig. 13. Again it indicates that this algorithm has successfully attenuated the seismic interferences.
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Fig. 3: Difference between Fig. 1 and Fig. 2

Fig. 4: Selected shot gathers

Fig. 5: After noise attenuation (FXEDIT)

Fig. 6: Selected CMP gathers after NMO

Fig. 7: After noise attenuation (FXEDIT)

Fig. 8: Difference between Fig. 6 and Fig. 7

Fig. 9: Stacked section

Fig. 10: After noise attenuation (FXEDIT)
High-amplitude noise attenuation

Two techniques to attenuate both non-coherent and coherent high-amplitude noises have been successfully implemented in this paper. For non-coherent high-amplitude noises attenuation, we use the strategy that the frequency components contaminated by strong amplitude noises are recovered by using a projection filter. For coherent high-amplitude noise attenuation, we use the strategy that first estimates the coherent noises and then adaptively subtract them from the data by using a pattern-based adaptive subtraction technique. Production implementations show encouraging results.

Acknowledgements

We would like to thank Weihan Yang, Jerry Young and Bruce Ver West for their discussions, Xiaogui Miao and Xin Huang for their assistants at early stage. We also thank Juneau Exploration, L.P. for permission to show their land data.

References


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