SPATIAL PREDICTION FILTERS FOR ATTENUATION OF SEISMIC INTERFERENCE NOISE

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1. ABSTRACT

The interest in the subject of time series analysis started in mid 1920s. The use of real valued prediction filters for predicting and attenuating temporal reverberations present in the recorded seismic signals, known as deconvolution, emerged in mid 1950s. The use of complex valued prediction filters along space axis on constant frequency seismic data for coherent signal prediction and random noise attenuation took place in mid 1980s. When coherent noise can be viewed from a dimension where it is incoherent then a similar filter can be used to attenuate such noise. Here we present the application of this idea to the attenuation of strong coherent noise, known as interference noise, generated by other seismic boats surveying the same area.

2. INTRODUCTION

One of the earliest published papers on time series analysis was done in 1927 by Yule[1] for analysis of sun spots. This is followed by pioneering development of deconvolution methods by Geophysical Analysis Group[2] at MIT between 1952-1957. A good review and exposition of geophysical signal analysis methods on time series can be found in a book by Robinson and Treitel[3]. In these methods repetitive portions of the real valued seismic wavelet are predicted and suppressed on seismograms (known as “traces”). In 1980’s we saw the application of prediction filtering[4,5] along the space direction on complex valued samples of the Fourier transformed data for attenuation of random noise on final data volumes (know as stack) of 2D data. These techniques are known as f-x prediction filtering in the seismic industry. Later these methods were extended to 3D[[6,7]] There are many different implementations of prediction filtering, i.e., the ones that use windowed autocorrelations, pre- and post-windowed autocorrelations, non-windowed autocorrelations (also known as “modified covariance method”[8]). In addition to causal (one-sided) filter design in post stack random noise attenuation, methods using non-causal (two-sided) filters also emerged [9].

In addition to random noise there are various noise types that need to be attenuated on seismic data. Particularly, seismic interference (SI) noise originating from other marine seismic crews surveying the same area creates many difficulties for seismic crews and needs to be attenuated. For reflection times greater than a few seconds below the water bottom time this high-energy noise overrides weak reflections and is harmful to many pre-stack processes, among them, surface multiple prediction, pre-stack migration, and AVO analysis. Therefore, such high amplitude noise needs to be attenuated beforehand.

Zones of data that contain such noise must first be identified (detection) and then the noise must be attenuated; during this process, one must make sure that the underlying signal is not attenuated. Seismic interference noise, while very coherent in the common shot domain, is incoherent in the common offset or common receiver domains, especially when small time windows are used, provided the shooting times of the recording vessel and the interfering vessel are not synchronized. Since we have a well-established tool, f-x prediction filtering (PF) mentioned previously, to attenuate incoherent noise it is natural to use it to attenuate SI noise.

Thinking along these lines common offset and common receiver domain f-x prediction filters were used[10] to attenuate SI noise in these domains in a cascaded fashion. We might refer to this technique as a crossline f-x prediction method, crossline being the direction from shot to shot. This method, like many others in the seismic industry, assumes the seismic signal to be predictable in these domains. Recently[11,12] magnitude threshold guided detection of noisy shots in the frequency-shot-receiver (f-x-y) domain followed by prediction and subtraction of inline coherent SI noise with very short (1-point forward or, equivalently, 3-point forward-backward) f-x prediction filters was done. This was followed by an application of an f-x-y prediction filter to the frequency slice.

3. THE METHOD

In the prediction filtering method that works in common offset and common receiver domains[10] strong amplitudes in the samples contaminated with SI noise are likely to bias the PF estimate, reducing the effectiveness of the filter to attenuate SI noise and/or preserve the underlying signal. In the amplitude threshold method [11,12], i.e., in comparing the average shot magnitude to the average slice magnitude as well as the average of magnitudes of the neighboring shots, one may get into trouble when there is a linear trend in average shot magnitudes. This trend can be eliminated if one looks at the noise output of the crossline prediction filters instead. This is the first stage in our method. From these samples common shot noise magnitudes are calculated and shots that contain noise above a certain percentage of the average noise in the slice are flagged. On each flagged shot, a 1-point PF is designed and applied independently in forward as well as backward direction to predict (and later subtract) the SI noise". The filter, p, is obtained from

$$p = \frac{a_1}{a_0}$$

where a_0 and a_1 are 0^{th} and 1^{st} lag of complex autocorrelations. The use of separate forward and reverse prediction filters preserves smooth amplitude variations in coherent noise being predicted.

The output of this process is then used as the input to a second crossline prediction filter. Note that the crossline prediction filter design of this stage is the same as the crossline prediction filters of the stage mentioned previously. These filters are designed as follows: Let **P**$=[p_1,p_2,\ldots,p_N]^T$, be the prediction filter of length N. Let the corresponding prediction error filter of length N+1 be **F**$=[f_0,,f_1,\ldots,f_N]^T$. This filter is designed from windowed autocorrelations $a_0,a_1,\ldots,a_N$ using Yule-Walker normal equations:

$$\begin{bmatrix} a_0 & a_1 & \ldots & a_N \\ a_1^* & a_0 & \ldots & a_{N-1} \\ \ldots & \ldots & \ldots & \ldots \\ a_N^* & a_{N-1}^* & \ldots & a_0 \end{bmatrix} \begin{bmatrix} f_0 \\ f_1 \\ \ldots \\ f_N \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ \ldots \\ 0 \end{bmatrix}$$

where * denotes complex conjugation. Prediction filter, **P,** is then obtained by:

$$\begin{bmatrix} p_1 \\ p_2 \\ \ldots \\ p_N \end{bmatrix} = \begin{bmatrix} -\frac{f_1}{f_0} \\ -\frac{f_2}{f_0} \\ \ldots\ldots \\ -\frac{f_N}{f_0} \end{bmatrix}$$

Note that, here too, one such filter is designed and applied in the forward and backward domains independently to allow prediction of events that may be varying in amplitude along the space direction.

4. FIELD DATA EXAMPLES

We have tested this method on quite a few sail lines from the Gulf of Mexico. A recorded shot from a survey that was contaminated with SI noise is shown in Figure 1.

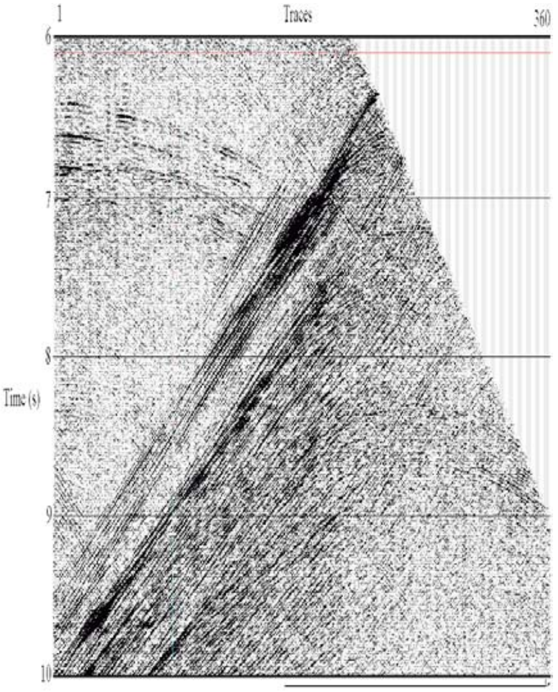

Figure 1: A shot record with seismic interference noise.

The diagonally oriented strong energy is the interference noise from another boat. The output of our method and the difference between input and output are given in Figures 2 and 3 respectively. At places where signal and high amplitude SI noise are present together, the process preserves signal while attenuating SI noise. Also, note the zero differences in windows where no data was flagged as noisy (upper left portion of Figure 3) demonstrating that the input was not altered.

Interference noise may contaminate stack sections as well since noise leaks into stack sections due to its often aliased nature and its high energy. Figure 4 shows the stack of seismic interference noise contaminated shots from another line in the Gulf of Mexico. Interference noise is clearly visible. Figure 5 is the stack of the seismic interference noise reduced shots. Figure 6 is the difference between Figures 4 and 5 which shows that seismic interference noise leakage to stack was significant and that it was detected and suppressed by the process.

5. CONCLUSIONS

We have presented a frequency-shot-offset (f-x-y) domain method that combines inline and crossline f-x prediction filters in detecting and attenuating strong seismic interference noise. The method is particularly suited to application at later times on the seismic record where the interfering noise has much higher amplitudes than the underlying reflections. After this process, noise residues are reduced to levels where they can be expected to pose no further problems to most pre-stack processes.

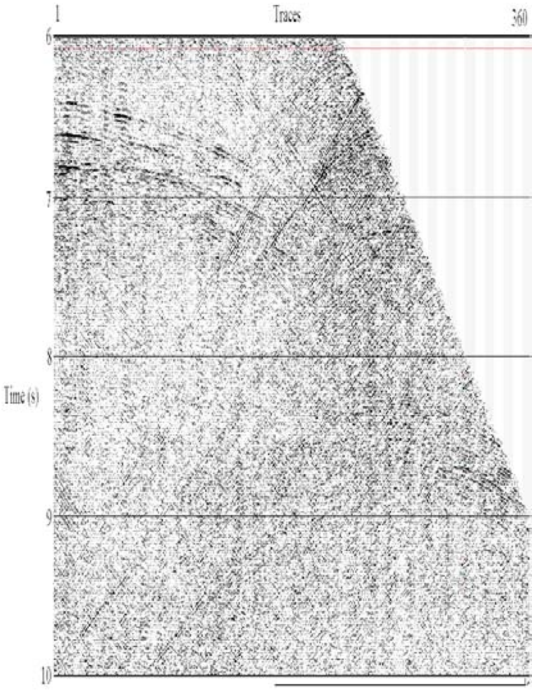

Figure 2: Same shot after seismic interference noise attenuation.

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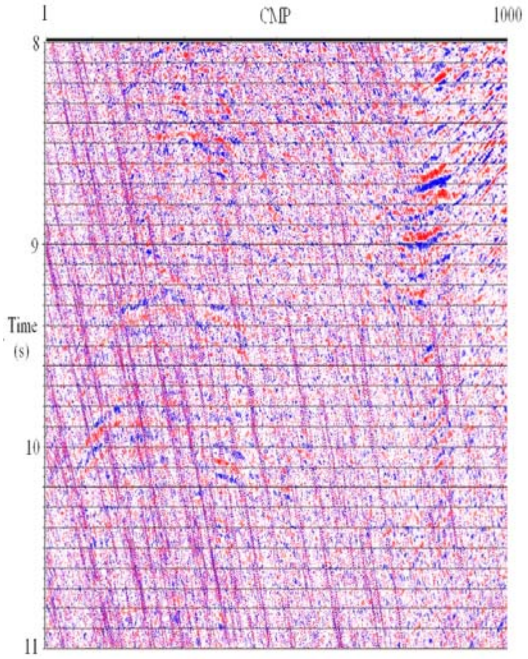

Figure 4: Stack of noisy shots.

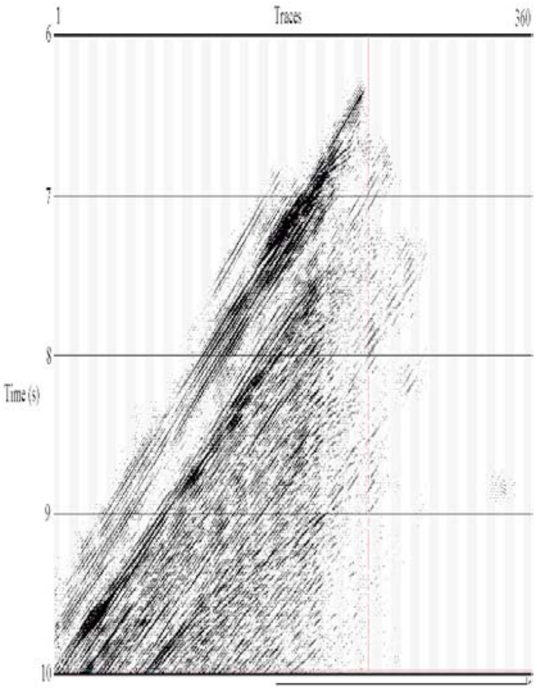

Figure 3: Seismic interference noise detected by the process.

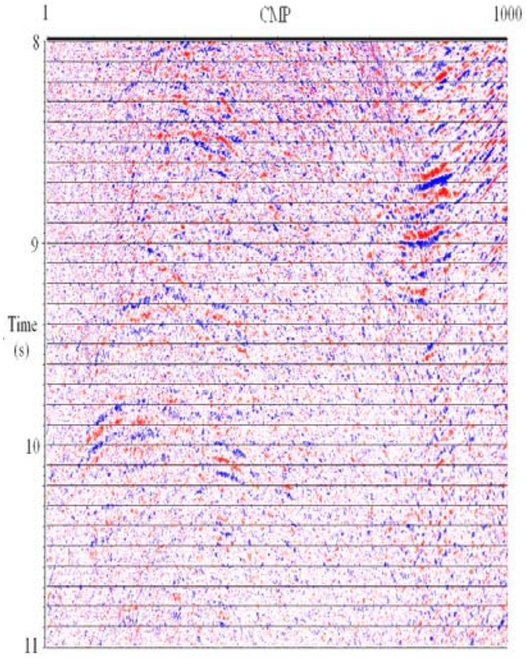

Figure 5: Stack of seismic interference noise attenuated shots.

6. ACKNOWLEDGMENTS

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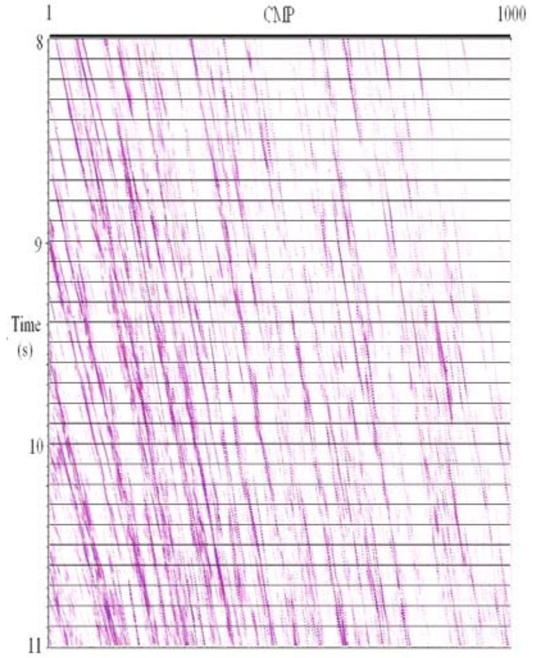

Figure 6: The difference between stack of noisy shots and stack of seismic interference noise attenuated shots.