Edge-preserving lateral prediction for noise attenuation based on classification

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Summary

Lateral prediction methods are widely used for random seismic noise attenuation. In general, these methods smear the discontinuity in seismic data. In order to preserve the discontinuity, I propose an edge-preserving lateral prediction method by classifying every sample of the seismic data into three classes: the edge-at-left, the edge-at-right, and the no-edge-around. The classification is realized by using multiple filtering results, which are obtained by applying several lateral prediction filters on seismic data along different directions. Based on the classification results, these multiple filtering results are merged together adaptively to form the final edge-preserved filtering result. To illustrate the proposed method, it is used to improve the traditional frequency-space, or $f-x$ prediction (FXP) method. In this improved $f-x$ prediction method (IFXP), two filtering results, which are obtained by the forward and backward filters respectively, are fused together with two adaptive weights, compared with two fixed weights used by the traditional FXP.

Introduction

The separation of signal and noise is a central issue in seismic data processing. By improving the signal-to-noise ratio (SNR) of the seismic data, the results of subsequent processing or interpretation are much facilitated. The seismic noise is both random and coherent in nature, they can mask desired seismic signals and disguise subtle structural or stratigraphic features. Since the lateral continuity of seismic reflections is always used to distinguish the seismic signal from the background random noise, there are a lot of prediction filter based methods that are good at attenuating the random seismic noise. The prediction filter in $f-x$ domain, which is a standard industry method known as “FXDECON”, is a widely used seismic processing technique for random noise suppression. Canales (1984) introduced the $f-x$ prediction technique, and Gulunay (1986) further developed it based on Treitel’s complex series prediction work (Treitel, 1974). Abma and Claerbout (1995) introduced $t-x$ prediction method, and compared it with the $f-x$ method. Liu et al. (2014) proposed an adaptive prediction filtering in t-x-y domain for random noise attenuation using regularized nonstationary autoregression. The polynomial fitting (PF) method has been used for seismic noise attenuation (e.g. Liu et al., 2011) and coherent noise estimation (Lu et al., 2006) successfully. These PF methods estimate the coherent signal (noise) by fitting its amplitude along its trajectory with a polynomial. These signal predictability based methods (e.g., f-x deconvolution and PF method) have been successful in many areas. But they smear the discontinuities of the seismic data to a certain extent. Edge-preserving smoothing (EPS) method (Luo et al., 2002) is proposed to reduce the random noise while preserving the edges. AlBinHassan et al. (2006) extend the EPS method to 3D case. Structure-oriented filtering (Hocker and Fehmers, 2002), which is based on a simulated anisotropic diffusion process, can reduce the random noise while preserving the edges of geologic nature. Lavialle et al. (2007) proposed a seismic fault preserving diffusion method, which is a non-linear diffusion approach based on the definition of a partial differential equation, for a better detection of the seismic faults. Lu and Lu (2009) proposed an edge-preserving polynomial fitting

(EPPF) method leading to good signals and edges preservation. Yu and Wang (2013) introduced an edge-preserving noise reduction method based on Bayesian inversion framework.

In this paper, I propose an edge-preserving strategy for these lateral prediction methods. In general, one prediction method can obtain multiple filtering results by applying several lateral prediction filters on seismic data along different directions. For example, the FXP method obtains two filtering results by applying two prediction filters in both forward and backward directions in space. In the proposed method, the seismic data sample are classified into three classes: the edge-at-left, the edge-at-right, and the no-edge-around. One edge-at-left sample refers to there is an edge at the left side of this sample. One edge-at-right sample refers to there is an edge at the right side of this sample. And one no-edge-around sample refers to there is no edge around this sample. The feature vector of each sample, which is inputted into a classifier, are formed by using these filtering results along different directions. Based on the classification results, I obtain the edge-preserved filtering result by merging these filtering results along different directions together adaptively. To illustrate the proposed method, in the following section, the traditional FXP method is improved by merging two filtering results, which are obtained by the forward and backward filters respectively, with two adaptive weights.

Theory and Method

Let the clean seismic signal, the noisy seismic signal, and the noise be denoted as $s(i,j)$, $x(i,j)$ and $n(i,j)$, respectively, where i is the lateral position and j is the time. And the noisy seismic signal is given as follows:

$$x(i,j) = s(i,j) + n(i,j)\,. \tag{1}$$

In the traditional FXP method, two filtering results are obtained by applying two prediction filters in both forward and backward directions in space at first. Here the forward filtering result is denoted as $\bar{s}_f(i,j)$, and the backward one is denoted as $\bar{s}_b(i,j)$. After that, for these traces that both filters are applied, the traditional FXP method obtains the filtering result $\hat{x}(i,j)$ by merging these two filtering results, $\bar{s}_f(i,j)$ and $\bar{s}_b(i,j)$, together with two fixed weights:

$$\hat{x}(i,j) = 0.5\bar{s}_f(i,j) + 0.5\bar{s}_b(i,j)\,\cdot \tag{2}$$

It is seen that the traditional FXP method can work well for these no-edge-around samples since they are predictable from both side. For these samples closing to an edge, in general, they can be well predicted by using the samples in the same side of this edge. In contrast, the prediction results obtained by using the samples in other side of the edge should not be good enough. In particular, we can expect that the filtering result $\bar{s}_b(i,j)$ of these edge-at-left samples will be closer to the clean signal $s(i,j)$, compared with the filtering result $\bar{s}_f(i,j)$. Similarly, we can also expect that the filtering result $\bar{s}_f(i,j)$ of these edge-at-right samples will be closer to the clean signal $s(i,j)$, compared with the filtering result $\bar{s}_b(i,j)$. In order to preserve the edges in seismic data, the proposed IFXP method obtains the filtering result $\hat{x}(i,j)$ by merging these two filtering results, $\bar{s}_f(i,j)$ and $\bar{s}_b(i,j)$, together with two adaptive weights:

$$\hat{x}(i,j) = \alpha(i,j)\bar{s}_f(i,j) + \beta(i,j)\bar{s}_b(i,j)\,, \tag{3}$$

where $\alpha(i,j)$ and $\beta(i,j)$ are the weights, and $\alpha(i,j)+\beta(i,j)=1$. The weight $\alpha(i,j)$ is set as

$$\alpha(i,j)=\begin{cases}0.5 & \text{no-edge-around}\\ 1 & \text{edge-at-right}\\ 0 & \text{edge-at-left}\end{cases}. \quad (4)$$

To obtain the classification of seismic data samples, I adopt a simple classifier based on the energies removed by the forward and backward filters:

$$e_f(i,j)=\left\|x(i,j)-\bar{s}_f(i,j)\right\|_2^2, \quad (5)$$

$$e_b(i,j)=\left\|x(i,j)-\bar{s}_b(i,j)\right\|_2^2. \quad (6)$$

In order to get a stable classification result for noisy seismic data, a 1D average filter, which is along the time direction, is applied on $e_f(i,j)$ and $e_b(i,j)$, respectively. The average filtering results are denoted as $\bar{e}_f(i,j)$ and $\bar{e}_b(i,j)$. After that, for every seismic data sample, I get a variable defined as:

$$c(i,j)=\frac{\bar{e}_f(i,j)}{\bar{e}_f(i,j)+\bar{e}_b(i,j)}. \quad (7)$$

The simple classifier used by the proposed method is

$$\begin{cases}x(i,j)\in\text{no-edge-around} & if\,(0.5-\sigma<c(i,j)<0.5+\sigma)\\ x(i,j)\in\text{edge-at-right} & if\,(c(i,j)\le 0.5-\sigma)\\ x(i,j)\in\text{edge-at-left} & if\,(c(i,j)\ge 0.5+\sigma)\end{cases}, \quad (8)$$

where σ is a threshold given by the user, and $0<\sigma<0.5$.

In summary, at first, the proposed method applies both forward and backward predictions respectively. Secondly, for the seismic data sample $x(i,j)$, the variable $c(i,j)$ is calculated according to equation 7. Thirdly, the classification of the seismic data sample $x(i,j)$ is achieved by the simple classifier shown in equation 8. At last, the final filtering result is obtained according to equation 3 and 4.

Examples

To demonstrate the performance of the proposed IFXP method, I apply it to a synthetic seismic data, and compare the results with those obtained by the FXP method. To evaluate the performance of the proposed method, the SNR of the filtering result is used, which is defined as:

$$\text{SNR}=10\log_{10}\left(\frac{\|\mathbf{s}\|_2^2}{\left\|\mathbf{s}-\tilde{\mathbf{s}}\right\|_2^2}\right), \quad (9)$$

where $\mathbf{s}$ is the clean signal, and $\tilde{\mathbf{s}}$ is the filtering result.

In the synthetic data example, the clean seismic data (figure 1a) is used to generate the noisy data ($SNR=5dB$) shown in figure 1b. There are five flat seismic events, one slant seismic event, and two faults in this synthetic data. For both FXP and IFXP methods, the prediction filter order is 6. For IFXP method, the threshold σ is 0.15. Figure 2a shows the result obtained by the IFXP method, and figure 2b shows the difference between the clean seismic data (figure 1a) and the result shown in figure 2a. The SNR of the result obtained by the proposed method is 11.36 dB. In comparison, figure 2c shows the result obtained by the FXP method, and figure 2d shows the difference between the clean seismic data (figure 1a) and the result shown in figure 2c. The SNR of the result obtained by the FXP method is 10.33 dB.

From figure 2, it is clear that the proposed method preserves the edges better, compared by the FXP method.

Conclusions

I have proposed a stratage to improve the traditional lateral prediction methods by preserving the edges further. I have illustrated the proposed method by appying it on the prediction method in f-x domain. The application results on synthetic seismic data show that the proposed method outperforms the traditional FXP domain. It is straightforward to extend the proposed method to any lateral prediction method in other domains.

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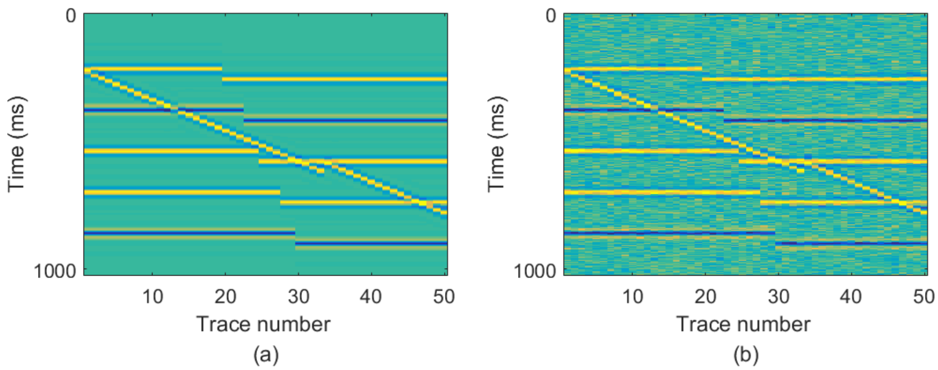

Figure 1: A synthetic seismic data example. (a) The clean seismic data, and (b) the noisy seismic data.

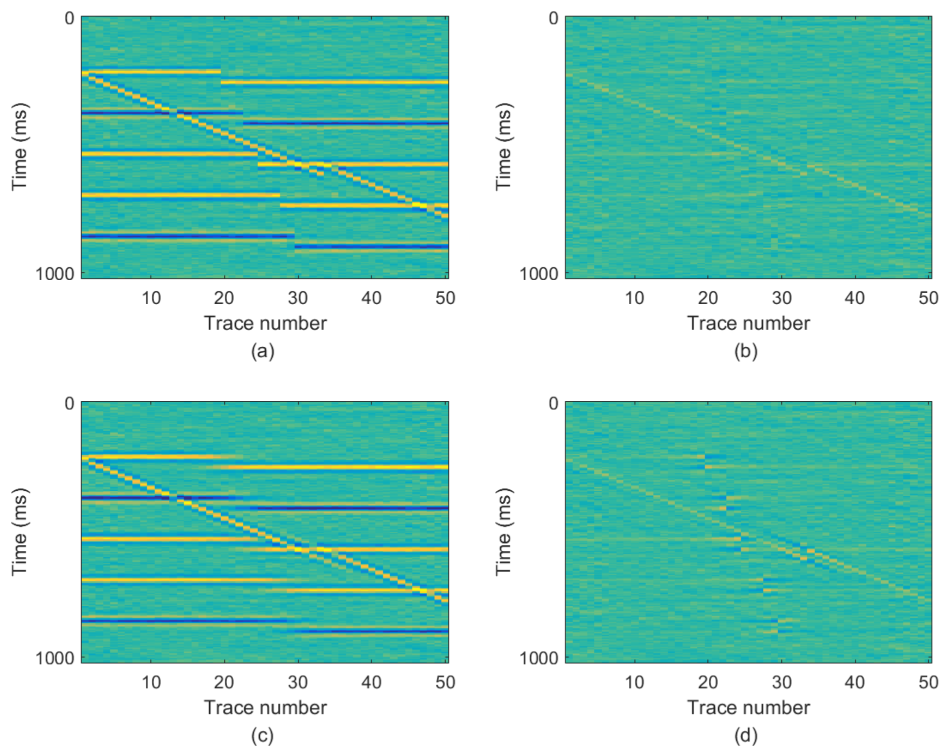

Figure 2: A synthetic seismic data example. (a) The result obtained by IFXP method, (b) the clean seismic data (figure 1a) minus the filtering result (figure 2a), (c) The result obtained by FXP method, and (d) the clean seismic data (figure 1a) minus the filtering result (figure 2c).

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