Introduction

During seismic data acquisition, seismic dataset are always polluted by random noise which comes from different noise sources. Thus, random noise attenuation plays a fundamental role in seismic data processing and interpretation (Neelamani et al., 2008; Qu et al., 2015; Chang et al., 2018). Over the past few decades, many denoising methods for random noise have been developed. Prediction-based methods use the predictable property of useful signals to build predictive filters for signal enhancement and noise suppression, for example, t-x predictive filtering (Abma et al., 1995), f-x deconvolution (Canales, 1984). The learning-based dictionaries have become increasingly popular for seismic data processing in recent years since their superior performances in adaptive learning that can sparsely represent the complicated seismic data (Sahoo et al., 2013). Beckouche et al. (2014) proposed a denoising approach by adaptively learning dictionaries from noisy seismic data. Mean and median filters utilize the statistical difference between signal and noise to reject the Gaussian white noise or impulsive noise (Gan et al., 2016).

For seismic denoising, there are many applications require filtering that can preserve edges. For this reason, many edge-preserving filters have been proposed. Basically, these edge-preserving filters can be divided into two categories. One is global optimization based algorithms, such as the total variation (TV) algorithm (Anagaw et al., 2012), the improved total variation algorithm (Gemechu et al., 2017). The other is local optimization based algorithms, such as s bilateral filter (Hale, 2011). These filters always try to estimate an output of a seismic data based on its neighbors. However, the seismic data being processed is located at the center of an operation window and other seismic data in the operation window are its neighbors. This causes blurring of edges in seismic data. In this paper, we propose to apply a preserved edges algorithm to denoising seismic random noise, which is called side window filtering (Yin et al. 2019). First, we introduce the basic formulation of the side window filtering (SWF). Then, we also apply SWF with box filter to denoise seismic data. Finally, two examples show that the SWF algorithm can significantly preserve edges of seismic data and suppressing random noise.

Method

Local based filters use linear approximation or non-linear approximation to estimate the output of the noisy seismic data. Box filter uses a common linear approximation based seismic data filtering operation assumes that seismic data is piecewise linear and approximate a sample point as the weighted average of its neighbor sample points over a local window:

$$\hat{Y}_j = \sum_{i \in N_j} w_{ji} X_i$$  

(1)

where $N_j$ is the local window centered at the sample point $j$, $w_{ji}$ is the weight kernel, $X_i$ is the intensities of the input seismic data $X$, $\hat{Y}_j$ is the output seismic data $Y$ at location $j$, respectively. The discrepancy between the filter output and the original seismic data can be formulated as the following cost function :

$$L_i = ||Y_j - \hat{Y}_j||_2^2$$  

(2)

Different weight kernels will result in different filtered output seismic data, and in most cases the task of designing the filtering algorithm is to estimate the weights-ideal seismic data. A new edge-preserving strategy, called side window filtering (SWF) technique, is proposed by Yin et al. (2019). The SWF consider each target sample point as a potential edge and generate multiple local windows (named as side windows) around it, each of which aligns the target point with a side or a corner (instead of the center) of the window. The output of SWF is a linear combination of the neighbors in one of the side windows which can best approximate the target sample point.

The definition of a side window is shown in Figure 1(a), with parameters $\theta$ and $r$. $\theta$ is the angle between the window and the horizontal line, $r$ is the radius of the window, $\rho \in (0, r)$ and $(x, y)$ is the position of the target sample point $j$. $r$ is a user-defined parameter and it will be fixed for all the
side windows. By changing \( \theta \) and fixing \((x, y)\), we can change the direction of the window while aligning its side with \( j \).

To simplify the calculation, eight side windows is defined in a discrete case, as shown in Figure 1(b)∼(d). These eight specific windows correspond to \( \theta = k \pi/2 \), \( k \in [0, 3] \). It is worth pointing out that there is significant flexibility in designing the size, shape and orientation of the side windows. And the only specific requirement is that the point under consideration is placed on the side or corner of the window.

![Figure 1](image)

**Figure 1** Definition of side window. (a) The definition of side window in continuous case. (b) The northwest (red rectangle), northeast (blue rectangle), southwest (green rectangle) and southeast (black rectangle) side windows. (c) The left (red rectangle) and right (black rectangle) side windows. (d) The up (red rectangle) and down (black rectangle) side windows.

By applying a filtering kernel \( F \) in each side window, we can obtain eight outputs, denoted as \( \tilde{Y}_{j,\theta,\rho} \), where \( \theta = k \pi/2 \), \( k \in [0, 3] \) and \( \rho \in (0, r) \):

\[
\tilde{Y}_{j,\theta,\rho} = F(X_j, \theta, \rho, r)
\]

To preserve the edges means that we want to minimize the distance between the input and the output at an edge. Therefore, we choose the output of the side window that has the minimum distance to the input intensity as the final output:

\[
\bar{Y}_{SWF} = \arg\min_{\tilde{Y}_{j,\theta,\rho}} \|X_j - \tilde{Y}_{j,\theta,\rho}\|_2^2
\]

where \( \bar{Y}_{SWF} \) is the output of SWF.

**Examples**

In this section, the SWF method is applied to two field seismic data set. Figure 2 shows the first example. Figure 2a is the clean seismic data. We added random noise with SNR = 0.5 to the clean seismic data (Figure 2b). Then we have employed the SWF method using the synthetic dataset, and the denoised output is shown in Figure 2c. We observe that the denoised output agrees reasonably well with Figure 2a. On the other hand, the SWF can preserve edges and remove noises at the same time. The residual data (Figure 2d) calculated from noisy data and denoised data shows that there is no
edges in noise data. And Figure 2e is the residual data between Figure 2a and Figure 2c. These results further demonstrate the excellent edge preserving property of the new side window technique.

![Figure 2](image1)

**Figure 2** Field seismic dataset, (a) Seismic data, (b) noise data, (c) denoised data, (d) noise data between (b) and (c), and (e) noise data between (a) and (c).

The second example (Figure 3) has been selected to validate the performance of the SWF denoising method. Figure 3a is the clean seismic data. We added random noise with SNR = 1.0 to the clean seismic data (Figure 3b). The results from using the SWF as shown in Figure 3c allows for the character of the reflectors to become more apparent while not losing any of their energy to the estimated noise (Figure 3d). And fault edges are more shaped and clearer. It demonstrates that the SWF method can be just as effective for suppressing random noise in seismic data and effectively preserve edges of seismic data in the area of complex structures, but also preserves the amplitude of the curved events and does not smear seismic energy across the sharp discontinuities. The quality of the noise attenuation in local regions is particularly promising.

![Figure 3](image2)
Figure 3 Field seismic dataset, (a) Seismic data, (b) noise data, (c) denoised data, (d) noise data between (b) and (c), and (e) noise data between (a) and (c).

Conclusions

In this paper, we have presented an SWF for random noise attenuation in seismic data. Window based processing is one of the most common operations. Traditional practices almost always align the center of the window with the point under processing. We show that in seismic denoising, the side or the corner of the operation window instead of the center should be aligned with the sample point under processing and propose the side window filtering (SWF) technique. By denoising performance of field seismic data, this proposed method can obtain very clean denoised image and preserve edges.

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References