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Improvement of S/N Ratio of Seismic Data by Multi-channel Wiener Filter Algorithm

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Abstract. Noise reduction or cancellation is important for getting clear and useful signals. This paper deals with the implementation of the multi-channel wiener filter algorithm for noise suppression of seismic data. Known the velocity of reflection event, utilizes the resemblance of reflection signal in each seismic trace, the multi-channel wiener filter algorithm is effective in enhance reflection event and suppress the random noise. This algorithm is used to CDP gathers and the simulation shows the method is effective.

Introduction

On the base of keeping the resolution ratio, how to remove the noise and get the useful signal from strong noise, is a problem attended by people[1]. As long as the development of seismic exploration, the target of exploration is increasingly focused on the deep area, the energy of reflected signal becomes weaker. When the reflection seismic signal is submerged in the random noise, the reflection event is difficult to be tracked [2,3,4], existing technologies sometimes can not hold the useful signal. Recently, people developed a new technology of chaotic oscillator which can detect the existence of reflection event while the signal to noise ratio is as lower as -8dB and can confirm the velocity[5]. Based on this technology, we use multi-channel wiener filter algorithm to suppress the random noise.

Theory and Method

In the multi-channel wiener filter algorithm [6,7,8]we assume the input trace is n, the out put trace is m, define the input signal as $X(t)=[x_1(t),x_2(t),\cdots,x_n(t)]^T$, where $x_i(t)(i=1,2,\cdots,n)$i s ith channel; the desired output signal as $Z(t)=[z_1(t),z_2(t),\cdots z_m(t)]^T$, where $z_i(t)(i=1,2,\cdots,m)$i s ith channel; the output signal as $Y(t)=[y_1(t),y_2(t),\cdots,y_m(t)]^T$, where $y_i(t)(i=1,2,\cdots,m)$is ith c hann-el; the multi-channel filter factor as $h_{ji}(t)(j=1,2,\cdots,m;i=1,2,\cdots,n)$, written in matrix for m as

$$H(t)=\begin{bmatrix} h_{11}(t) & h_{12}(t) & \cdots & h_{1n}(t) \\ h_{21}(t) & h_{22}(t) & \cdots & h_{2n}(t) \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1}(t) & h_{m2}(t) & \cdots & h_{mn}(t) \end{bmatrix} \tag{1}$$

According to the principle of linear filter, we can obtain the following equation:

$$Y(t)=\begin{bmatrix} y_1(t) \\ y_2(t) \\ \vdots \\ y_m(t) \end{bmatrix}=\begin{bmatrix} \sum_{i=1}^{n} h_{1i}(t)*x_i(t) \\ \sum_{i=1}^{n} h_{2i}(t)*x_i(t) \\ \vdots \\ \sum_{i=1}^{n} h_{mi}(t)*x_i(t) \end{bmatrix} \tag{2}$$

In the single channel wiener filter algorithm, the problem is how to choose filter factor to make the mean-square error of the real output and the desired output minimum. In the multi-channel wiener filter algorithm, the problem is how to choose filter factor to make the sum error of each trace minimum.

We define the error of each channel as $e_j(t)\ (j=1,2,\cdots,m)$, where $e_j(t)=y_j(t)-z_j(t)$; define the mean-square error of j th channel as $Q_j\ (j=1,2,\cdots,m)$. Assuming the length of $x_i(t)$ is $k+1$, the length of filter factor is $s+1$, so the length of output of each channel $y_j(t)$ is $(k+s+1)$, and then Q_j is

$$Q_j=\sum_{t=0}^{k+s}e_j^2(t)=\sum_{t=0}^{k+s}\left[y_j(t)-z_j(t)\right]^2\ \ (j=1,2,\cdots,m) \tag{3}$$

and the summation of mean-square error of each channel is

$$Q=\sum_{j=1}^{m}Q_j=\sum_{j=1}^{m}\sum_{t=0}^{k+s}\left[y_j(t)-z_j(t)\right]^2 \tag{4}$$

The multi-channel filter factor can be obtained by differential of Q to $h_{ji}(t)$

$$\frac{\partial Q}{\partial h_{ji}(t)}=0\begin{pmatrix}1\le j\le m\\ i\le 1\le n\\ 0\le t\le s\end{pmatrix} \tag{5}$$

Using (4), we can obtain

$$\frac{\partial Q}{\partial h_{ji}(t)}=\frac{\partial Q_1}{\partial h_{ji}(t)}+\frac{\partial Q_2}{\partial h_{ji}(t)}+\cdots+\frac{\partial Q_m}{\partial h_{ji}(t)}=0 \tag{6}$$

According to (2), Q_j is only the function of $h_{ji}(t)$, so $\dfrac{\partial Q_v}{\partial h_{ji}(t)}$ is equal to zero if $j\neq v$:

$$\begin{cases}\dfrac{\partial Q}{\partial h_{1i}(t)}=\dfrac{\partial Q_1}{\partial h_{1i}(t)}=0\\ \dfrac{\partial Q}{\partial h_{2i}(t)}=\dfrac{\partial Q_2}{\partial h_{2i}(t)}=0\\ \vdots\\ \dfrac{\partial Q}{\partial h_{mi}(t)}=\dfrac{\partial Q_m}{\partial h_{mi}(t)}=0\end{cases} \tag{7}$$

Then we can obtain the following equation

$$\left[H(0)H(1)\cdots H(s)\right]\begin{bmatrix}R_{xx}(0) & R_{xx}(1) & \cdots & R_{xx}(s)\\ R_{xx}(-1) & R_{xx}(0) & \cdots & R_{xx}(s-1)\\ \vdots & \vdots & \ddots & \vdots\\ R_{xx}(-s) & R_{xx}(-s+1) & \cdots & R_{xx}(0)\end{bmatrix}=\left[R_{zx}(0)R_{zx}(1)\cdots R_{zx}(s)\right] \tag{8}$$

where $H(k)=\begin{bmatrix} h_{11}(k) & h_{12}(k) & \cdots & h_{1n}(k) \\ h_{21}(k) & h_{22}(k) & \cdots & h_{2n}(k) \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1}(k) & h_{m2}(k) & \cdots & h_{mn}(k) \end{bmatrix}$ is the filter factor matrix;

$R_{xx}(k)=\begin{bmatrix} r_{x_1x_1}(k) & r_{x_1x_2}(k) & \cdots & r_{x_1x_n}(k) \\ r_{x_2x_1}(k) & r_{x_2x_2}(k) & \cdots & r_{x_2x_n}(k) \\ \vdots & \vdots & \ddots & \vdots \\ r_{x_nx_1}(k) & r_{x_nx_2}(k) & \cdots & r_{x_nx_n}(k) \end{bmatrix}$ is the multi-channel auto correlation matrix of $x_i(t)$;

$R_{zx}(k)=\begin{bmatrix} r_{z_1x_1}(k) & r_{z_1x_2}(k) & \cdots & r_{z_1x_n}(k) \\ r_{z_2x_1}(k) & r_{z_2x_2}(k) & \cdots & r_{z_2x_n}(k) \\ \vdots & \vdots & \ddots & \vdots \\ r_{z_mx_1}(k) & r_{z_mx_2}(k) & \cdots & r_{z_mx_n}(k) \end{bmatrix}$ is a matrix of cross correlation of the desired output and the input. The solution of (8) is the multi-channel wiener filter factor.

At last, we discuss how to evaluate the performance of the algorithm[9]. We know that when the seismic channel is more than one, the minimum Q means each Q_i is minimum:

$$Q_{\min}=\sum_{j=1}^{m}Q_{j\min} \tag{9}$$

$$Q_{\min}=trR_{zz}(0)-tr\sum_{k=0}^{s}R_{zx}(k)H^T(k) \tag{10}$$

Assuming $\varepsilon=1-\dfrac{tr\sum_{k=0}^{s}R_{zx}(k)H^T(k)}{trR_{zz}(0)}$, then we obtain the standard mean-square error of the multi-channel wiener filter algorithm.

Example

The model of CDP gathers is presented like that: the signal of each seismic channel is: $x_1(t)=s(t-\tau_1)+n_1(t)$, $x_2(t)=s(t-\tau_2)+n_2(t)$, …, $x_n(t)=s(t-\tau_n)+n_n(t)$ where $s(t)$ is the Ricker wavelet, $n_i(t)$ is white noise.

Because of the effect of the random noise, we can not know the existence of the reflection event and the velocity according to the event[10,11,12]. First, the method of chaotic oscillator can confirm whether there is an event and the velocity, then the multi-channel wiener filter algorithm can eliminate the random noise.

The model parameters are (Fig.1):

·constant velocity for the whole model is 1500m/s;

·the travel time ranges from 0s to 3s;

·2000m maximum offset, 50m trace spacing;

·Ricker wavelet with peak value 1, with 25Hz dominant frequency;

·power of the random noise is 0.1W.

We use the multi-channel wiener filter algorithm to this model, the result is showed in Fig.2. The standard mean-square error is 0.0750. As shown in Fig.2, this algorithm can eliminate random noise, and improve the signal to noise ratio of seismic data. To be clearer, we choose one channel to compare the Ricker wavelet, Fig.3 shows the Ricker wavelet with 0.1W random noise, Fig.4 shows the ideal and real Ricker wavelet after denosing. Simulating shows the form of the signal is mainly recovered. The amplitude spectrum of the ideal and record Ricker wavelet is shown in Fig.5 and Fig.6.We can see that after filter, the amplitude spectrum resembles the ideal amplitude spectrum and the dominant frequency is the same.

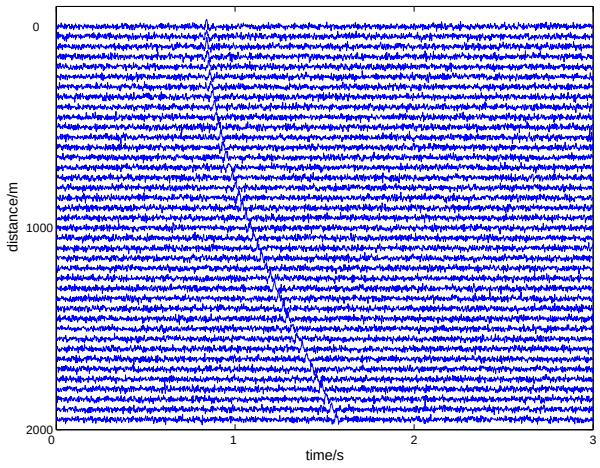

Fig.1 CDP gathers model

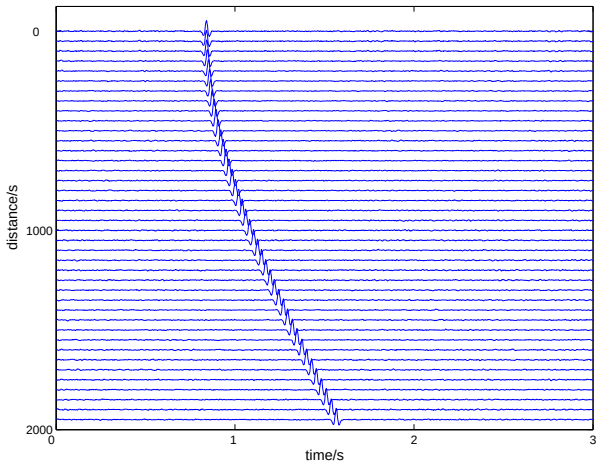

Fig. 2 The result of multi-channel filter of Fig.1

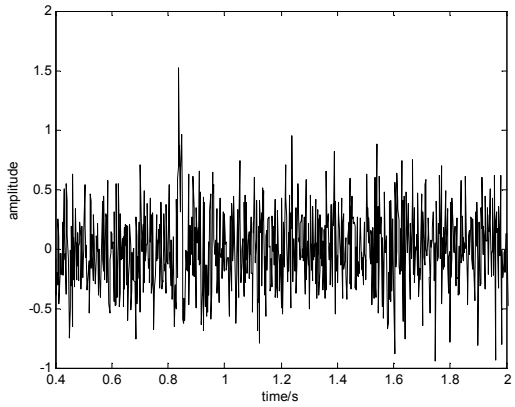

Fig.3 Ricker wavelet with 0.1W random noise

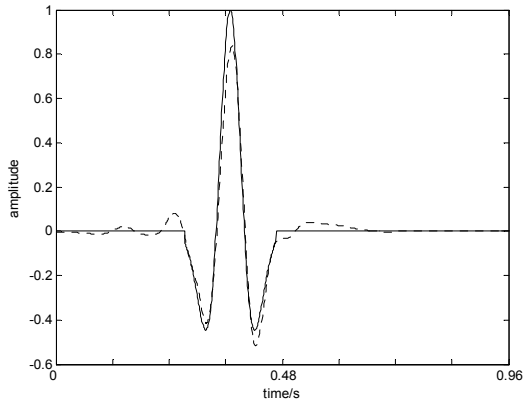

Fig.4 The full line is ideal Ricker wavelet, the dotted line is after denosing

When this algorithm is used to real seismic data, there are several problems to be considered. a. the length of the filter factor. Simulation shows that if the length is too small, the performance of algorithm is poor and vice versa. But while the length increases, the computation time also increases. So in the practice application, we have to take the two facts into consideration and then choose the appropriate length of filter factor. b. the number of trace of seismic data. The advantage of multi-channel wiener filter algorithm is that it uses the resemblance of the Ricker wavelet in each seismic trace. So when the seismic data is not enough, the performance will be affected.

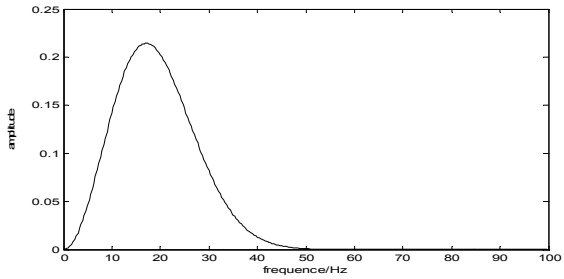

Fig. 5 Amplitude spectrum of ideal Ricker wavelet

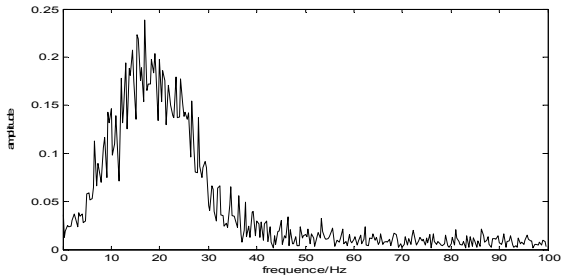

Fig.6 Amplitude spectrum of the wavelet after filter.

Conclusions

In this paper, multi-channel wiener filter is considered to suppress random noise of seismic data. Simulations show that this algorithm can efficiently eliminate random noise and improve signal to noise ratio of seismic data. But there are also some problems to be considered: a. in the real seismic

data, the wavelets in each channel are not the same and maybe have some amplitude aberrance or frequency aberrance; b. the reflection event maybe not continuous and the seismic data may exist more than one reflection event. Whether this algorithm can resolve the two questions are problems.

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