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CONTRIBUTION OF PRESERVATION LOW FREQUENCY INFORMATION ON STACKED SECTION: EXAMPLES FROM LAND AND MARINE SEISMIC DATA

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Summary. This paper presents an application of Wiener filtering to suppress the ground-roll and swell noises, which are with low frequency and high amplitude, included in land and marine seismic data. The noises always contaminate and make invisible the reflections especially in low frequency part of seismic data. The filtering of them without distorting the available frequencies is required in seismic data processing. For this purpose, the Wiener filter is designed to find the filter coefficients which are used to estimate the noises embedded in seismic data. Therefore, the noise estimation has been adaptively subtracted from the data to perform the filtering process. The applications of the method to both land and marine datasets show that the proposed filtering is effective in protecting available reflection signal and also provide a much improved quality of deep part of stack sections compared with the conventional classical band-pass filtering.

Introduction

Seismic data acquired for the exploration of subsurface structural, stratigraphic or hydrocarbon potential include many types of noise that distorts the valuable primary reflections. The amplitudes of noises are generally superimposed with that of the amplitude of reflection events especially at low frequencies. Two of them are ground roll noise in land which is the vertical component of the Rayleigh surface waves, and swell noise occurred in bad weather conditions in marine data. The main characteristics of noises are that they have high amplitude, low frequencies and lower propagation velocity. The lower frequencies represent the available reflections from deeper reflectors such as deep hydrocarbon bearing reservoirs and structural and stratigraphic layers. On the other hand low frequencies are very important to obtain high resolution subsurface images and for acoustical impedance inversion (*Kroode et al., 2013*). Thus, the lower frequency amplitudes of seismic data should be protected during the filter processing. In conventional processing, both noises are commonly filtered by using band-pass and transform based filters such as f-k (frequency-wavenumber), tau-p (tau-slowness), t-f (time-frequency) and etc. All these filters are mute-based filters depending on predetermined frequencies and velocities, that is, firstly the cut-off frequencies or velocities are defined and the amplitudes between them are eliminated by zeroing out or multiplying with a small numerical value.

Figure 1 shows schematically procedure of the both mute and estimate based filtering strategy. As shown in Figure 1a-b, the filtering of noises using frequency selective surgical mute is mostly practical and faster, but available amplitudes within the spectral band are also filtered or distorted unnecessarily, and therefore, the signal to noise ratio of the data is reduced. Nowadays, it is mostly preferred the estimation-based filtering (Deighan and Watts, 1997; Liu, 1999; Yuan and etc., 2022) instead of surgical mute-based filtering to prevent the available spectral information of seismic data as given in Figure 1c-d. One of the estimation-based filtering is the Wiener filter which is widely used for the purpose of deconvolution in the seismic processing (Yılmaz, 2001; Karslı and Bayrak, 2004; Dondurur and Karslı, 2012). The most important feature of Wiener filters is that they convert an input signal into any desired signal. Thus, it provides to adjust the amplitude and phase of the coherent noises in the data with a reference noise signal. If a noise model is determined, the Wiener filter successfully converts it to real noise including the seismic data. The main idea behind the proposed filter is to determine the noise component from data and then to attenuate it by arithmetical subtraction. In this paper, the importance and contribution of Wiener filtering technique in filtering of noises without surgical muting the available spectral information was introduced and some real examples obtained from the application with mute and without surgical mute-based techniques are presented comparatively.

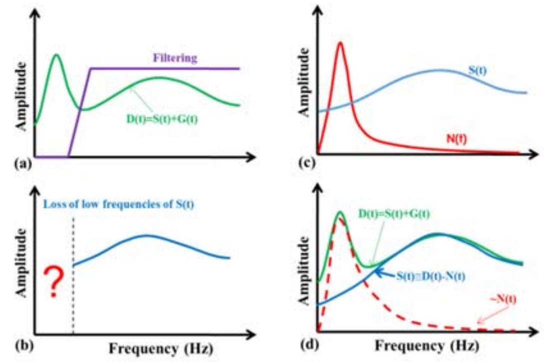

Fig. 1. Theoretical demonstration of the filtering of low frequency noises. (a, b) estimate and (c, d) mute based filtering strategies

Method and / or theory

The purposed strategy and mathematical base of Wiener filter application is briefly presented. When considering the seismic data model as D(t)=S(t)+N(t) (S(t) and N(t) are respectively signal and noise), N(t) should be estimated and is subtracted from D(t). For this purpose, Wiener filter coefficients which convert the an input to desired output are calculated solving the least square error function, E (or cost function) as follows,

$$E = \sum_{i=1}^{M} (N_t - N_{est})^2 \quad (1)$$

Here, N_t is a noise model which can be conveniently extracted from the data itself by a simple low-pass filtering (for marine data) and is used as sweep signal according to frequency characteristics of the noise (for land data). $N_{est}(t)=f(t)*D(t)$ (* shows convolution) which is called as estimated noise or actual output. Now the Wiener filter strategy focus on obtaining the estimation filter coefficients, f(t). After putting the N_{est} into the equation (1), it is solved taking the partial derivatives and setting them zero and rearranging the equations to obtain filter coefficients, f(t) as follows,

$$f=R^{-1}C \quad (2)$$

R is autocorrelation ($D_t \otimes D_t$) of the seismic data, D_t and is in Toeplitz matrix form. C is cross-correlation ($N_t \otimes D_t$) between noise model N_t and seismic data D_t. Now, the filtering is performed as,

$$S=D-f*D \quad (3)$$

This process is also known as deconvolution or inversion processing. The inversion of R matrix is solved using Levinson-Dubrin recursion algebra which is recursive, fast and stable and also very useful for large amount data (Claerbout, 1976). For stabilization of inversion, a quadratic regularization is used. More implementation details of the method can be found in Karslı and Bayrak (2004) and Dondurur and Karslı (2012).

Results and discussion

The application of the method is conducted for both land data with sampling interval 4 msec from Canadian and marine data with sampling interval 1 msec from Türkiye. Fourier spectra of the one of shot data sets including ground roll noise and swell noise are given in Figure 2a and 2b. As it is seen, the low frequency parts of the both data are dominated by the amplitude of noises (see elliptic area). If it is used a classical band-pass filter using proper cut-off frequencies to filter the noises, all amplitudes overlapping at low frequency part are inevitably muted. Such a filtering causes the loss of useful low frequency information of the data and weakens the reflection information located in the deep parts of the stacking sections.

The results of land and marine seismic data are presented in Figure 3 and 4. The stacked data were obtained by applying conventional seismic data processing including data loading, geometry definition, editing, band-pass filter with 15-60Hz (Fig. 3a) for land data, 20-213 Hz (Fig. 4a) for marine data and Wiener estimation filter (Fig. 1b) with 8-15Hz sweep signal as noise model for land data and low-pass filter output with the cut-off frequency f_c=15 Hz as noise model for marine data. The successive processes include CDP sort, velocity analysis, normal move out correction, stack and display with automatic gain control (500ms). As it is clearly seen that since the Wiener filtering protects the lower frequency contents of the data (see arrows), the amplitude of the deeper reflections increases and resolution is improved.

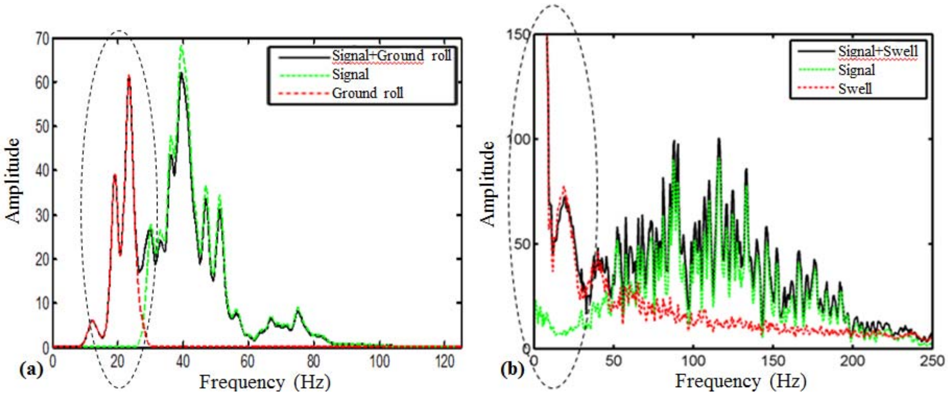

Fig. 2. An example of Fourier spectra from both land (a) and marine (b) seismic shot data

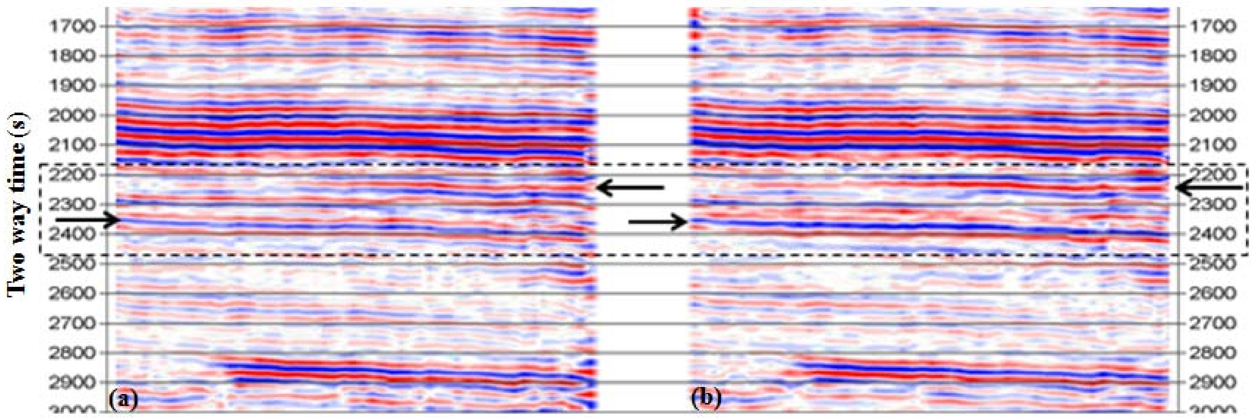

Fig. 3. Application results of filters on deep part of the stacked land seismic data. (a) Classical band-pass filter and (b) Wiener filter

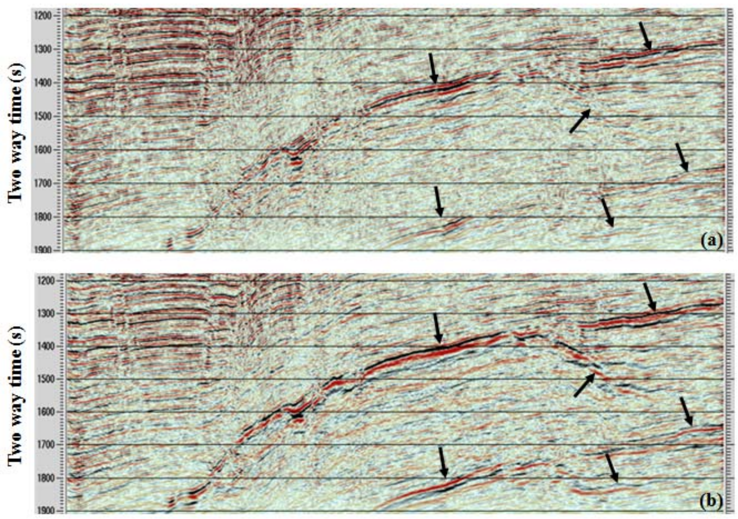

Fig. 4. Application results of filters on deep part of the stacked marine seismic data. (a) Classical band-pass filter and (b) Wiener filter

Conclusion

In this study, it was shown that Wiener filtering has effectively filtered the ground roll and the swell noises which overlap available reflections in low frequency band of seismic data. In order to indicate the performance of the proposed method, stacked sections were obtained using both the classical band-pass filtering and Wiener filtering. Outcomes from both filters are compared in terms of both quality of the final images and protection of useful information of data. The proposed filtering clearly improved the quality of stack sections and therefore provided more interpretable seismic section in terms of structural and hydrocarbon trap exploration, especially at deeper part of seismic data.

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