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Efficiency of complex trace analysis to attenuate ground-roll noise from seismic data

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ABSTRACT

Ground-roll, characterized by low frequency and high amplitude, is one of the most important issues in seismic data processing. Common methods to eliminate ground-roll noise from seismic data include frequency-based methods which pose filtering the whole signal. In addition, assuming being stationary signal which attended in filter is another disadvantage of those methods; however, in this paper a new method based on using Hilbert transform to address high-amplitude, low-frequency coherent noise is proposed. In this respect the conventional seismic trace can be viewed as the real component of a complex trace. Therefore, its envelope and normalized phase, as the input of running average, are easily calculated. On the other hand, complex trace-based filtering is approached to be a method distinguishing between coherent noise and reflections overlapping each other. This is done by setting a suitable length of window on running average in order to extract low frequency components from data.

1. Introduction

One of the most significant challenges in processing of seismic data is to filter different types of noises. Noise on seismic datasets can appear as a result of many different physical processes and, consequently, with many different seismic characteristics. Ground-roll is a surface wave whose vertical component is composed of dispersive Rayleigh waves whose different frequency components travel at different velocities, leading to long complex wave trains that change as the length of the path traveled increases (Beresford-Smith and Rango, 1988). The ground-roll propagates along the free surface at low group velocities and, when not accounted for in the acquisition design, often dominates seismic gathers as high-amplitude, low-frequency coherent noise (Welford and Zhang, 2004).

As seismic data sets are often contaminated with high amplitude and low-frequency dispersive ground-roll, many methods have been introduced to attenuate this coherent noise. Although the right choice of attenuation techniques is a matter of trial and error (Sheriff and Geldart, 1995), there are some methods that have been mentioned by seismic data processors such as using inverse problems and prediction error filters (Guitton, 2002), S and x-f-k transforms (Askari and Siahkoohi, 2008), wavelet transform (Deighan and Watts, 1997), polarization filters (Shieh and Herrmann, 1990), applying empirical mode decomposition in *f*-*x* domain (Bekara and van der Baan, 2009), polarization filtering (Jin and Ronen, 2005), interferometric filtering (Dong et al., 2006; Halliday et al., 2007), local-time frequency decomposition (Liu and Fomel, 2013), Karhunen–Loeve transform (Liu, 1999), SVD filtering (Porsani et al., 2010) and Wiener–Levinson algorithm (Karslı and Bayrak, 2004).

Nevertheless, fundamental processing methods include frequency filtering, windowed frequency filtering, and *f* -*k* filtering which are based on Fourier transform that uses orthogonal basis functions that have perfect localization in frequency but infinite extent in time (Deighan and Watts, 1997).

This paper, however, suggests a new approach to address the issue of eliminating ground-roll noise using complex trace analysis along with running average filter. Although complex trace analysis, as one of the most significant tools in analyzing signal, with particular emphasis on its applicability in extracting instantaneous attributes, can be considered as an auxiliary tool in order to process a variety of seismic noises, its application generally is restricted in seismic data interpretation. In this sense, Taner et al. (1979), for example, pointed out that complex trace analysis is a method that illustrates the role of color in conveying seismic information to an interpreter.

However, compared with frequency-based de-noising methods which filter the input trace, complex trace-based filtering (CTF) method efforts to preserve the frequency content of reflections and ideally affects the part needed to be filtered through selecting the best size for introduced *time* and *phase window* of running average, results in approaching the filter to main lobe indicating ground-roll.

The performance of CTF algorithm strongly depends on the length of windows, so a method to choose its best length and its application to

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attenuate ground-roll noise is discussed in the following sections with examples of synthetic and field seismic data.

2. Complex trace analysis

Complex trace analysis, a mathematical method to determine seismic attributes including reflection strength and instantaneous frequency, by using the Hilbert transform, has been discussed in different literatures and papers in detail (Aritman, 2001; Shtivelman et al., 1986; Taner et al., 1979). Basically, complex trace or analytical trace has been introduced for signal processing in the context of communication theory (Taner et al., 1979).

The use of the complex trace makes it possible to define instantaneous attributes—amplitude, phase, and frequency, being basic concepts in all the questions dealing with modulation of signals appearing especially in communications or information processing (Picinbono, 1997). This is done by ascribing the seismic trace $s(t)$ to the real part of the analytical signal and its Hilbert transform $H\,(s(t))$, the conjugate part of the seismic trace, to the imaginary part of $S\,(t)$ (Schimmel and Paulssen, 1997) as follow:

$$S(t) = s(t) + js^{*}(t) \tag{1}$$

It follows that if $s(t)$ and $s^{*}(t)$ are known, we can calculate the reflection strength, or envelope (Aritman, 2001). The analytical signal can also be stated with time-dependent amplitude $A(t)$ and phase $\theta(t)$:

$$s(t) = A(t)\cos\ \theta(t) \tag{2}$$

$$s^{*}(t) = A(t)\sin\ \theta(t) \tag{3}$$

and, therefore, complex trace is:

$$S(t) = A(t)\cos\ \theta(t) + j\ A(t)\sin\ \theta(t) = A(t)\ e^{j\theta(t)} \tag{4}$$

To avoid losing any frequency components, however, the real seismic trace can be expressed as a function of time-dependent amplitude and a time dependent phase (in Eq. (2), $s(t)$, $A(t)$and $\theta(t)$ represent seismic trace, envelope and instantaneous phase, respectively). Therefore, the actual signal can be reconstructed using linear multiplication of the envelope and normalized phase—the cosine of instantaneous phase (Karslı et al., 2006).

Although the envelope is a positive function of time and describes the energy distribution along the trace (Shtivelman et al., 1986), it would be altered into an oscillating function. In this respect, low frequency component by means of the running average, a method to make a signal smoother, within a given-time window, is computed and subtracted from the envelope to obtain the so called group trace (Karslı et al., 2006) as follow,

$$g(t) = A(t) - l(t) \tag{5}$$

where $g(t)$ is group trace, and $l(t)$ is the output of running average. Fig. 1 illustrates a typical seismic trace into its instantaneous attributes.

However, besides time window used in running average to obtain the envelope indicating ground-roll, *phase window* for extracting the normalized phase is also executed on data. Its reason rests on the idea that without removing the ground-roll characteristics from seismic data, the noise would again attend the signal, followed by contaminating reflections (see Fig. 9c).

The output from the running average is undeniably sensitive to change the window length and it performs as a function of frequency content of the input signal (Karslı et al., 2006).

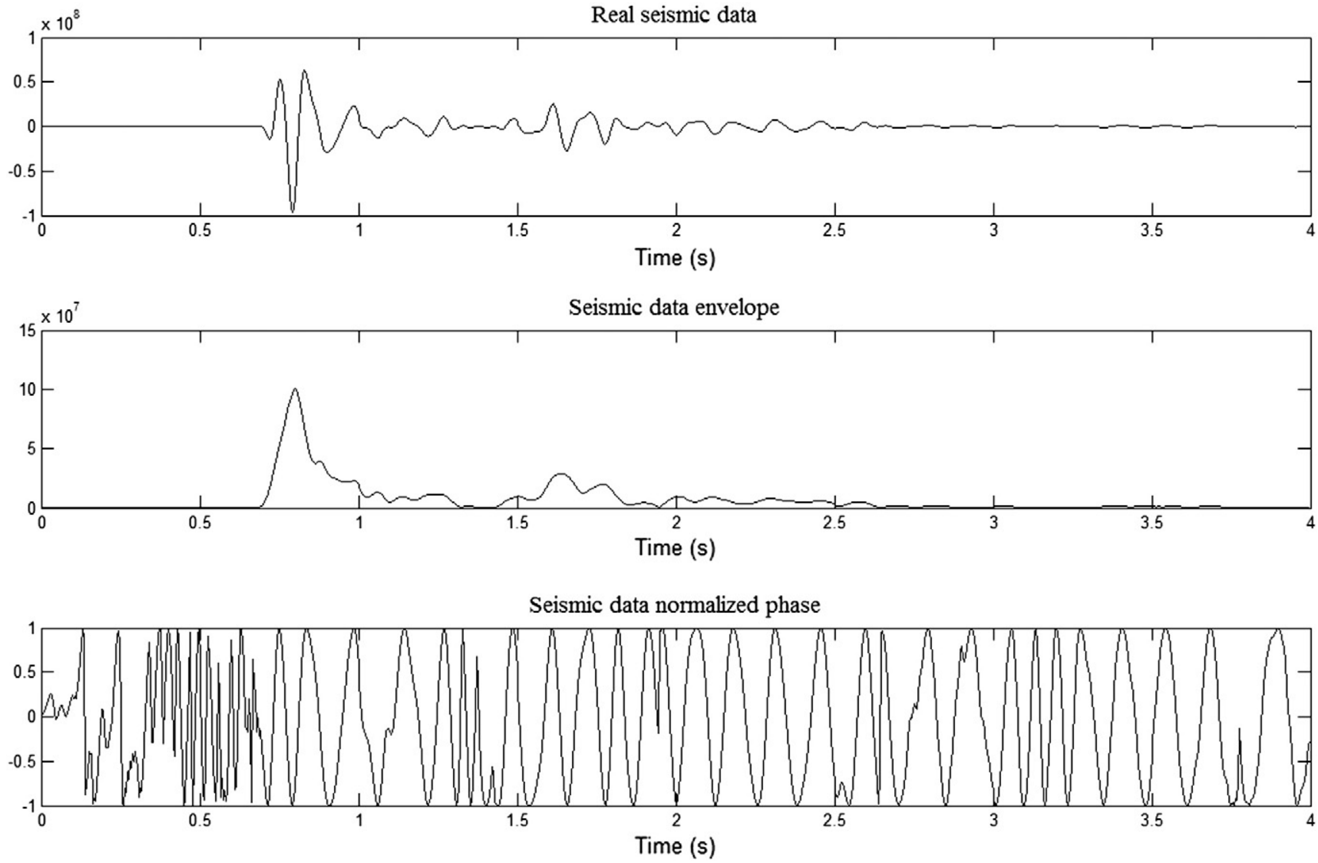

Fig. 1. Transformation of a typical seismic trace into the envelope and normalized trace, respectively from up to down.