Investigation of probe waveforms for Wiener spiking de-convolution

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Abstract

Wiener spiking de-convolution (WSD) is extensively used in radar and sonar applications to improve the temporal resolution. In WSD filtering also known as Wiener predictive filtering the source wavelet or probe signal is de-convolved to obtain the hyper sharp peaks in the time domain. The sharper the peaks the higher the time resolution.In this paper the peaks obtained for the different probe signals using WSD are investigated and results are presented.

KEYWORDS –WSD, chirp Waveform, MLS

I. Introduction

The Weiner spiking de-convolution was first developed by Norbert Wiener developed as a statistical process which separated radar signals buried in noise.The technique was originally known as Wiener prediction filtering. The inverse process of prediction error filtering, is called as de-convolution. Today, WSD is the most commonly used process for processing seismic data containing several reflected signals [1-4]. The main objection of WSD filtering is to design a filter that de-convolve the source/probe wavelet. The probe signals used for the analysis are sinusoidal, square waveform, chirp signal and maximum length sequence (MLS).

The rest of the paper is organized as follows. Proposed technique is given in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

II.PROPOSED ALGORITHM

Wiener spiking deconvolution is based on the simple, one-dimensional, plane-wave convolutional model of the seismic trace. In the WSD model, an input acoustic signal/electromagnetic signal is transmitted through the layered structure and reflections are recorded [5]. The simplest representation consists of an average wavelet s(t) convolved with a reflection coefficient series r(t). This noise free trace is given as:

$x(t) = w(t)*r(t)$-------------------(1)

This model though very simple yet provides a good visualization and understanding of the reflection process.

Least-squares deconvolution filter design can be represented in the following way. The WSD filter attempts to reshape the input seismic trace s(t) into the desired output y(t) by minimizing the mean-squared error I between the desired output and the actual filter output k(t). The actual output is simply the input s(t) convolved with the filter a(t). The technique with type 1 desired output is called spiking deconvolution. Cross-correlation of the desired spike (1, 0, 0, …, 0) with input wavelet (x_0, x_1, x_2, …, x_{n-1}) yields the series (x_0, 0, 0, …, 0).

The generalized form of the normal equations (2) takes the special form [6-8]:

$$\begin{pmatrix} r_0 & r_1 & r_2 & \dots & r_{n-1} \\ r_1 & r_0 & r_1 & \dots & r_{n-2} \\ r_2 & r_1 & r_0 & \dots & r_{n-3} \\ . & . & . & r_0 & . \\ r_{n-1} & r_{n-2} & r_{n-3} & \dots & r_0 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ . \\ a_{n-1} \end{pmatrix} = \begin{pmatrix} g_0 \\ g_1 \\ g_2 \\ . \\ g_{n-1} \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The (2) in case of WSD filtering becomes (3) and is given as:

$$\begin{pmatrix} r_0 & r_1 & r_2 & \dots & r_{n-1} \\ r_1 & r_0 & r_1 & \dots & r_{n-2} \\ r_2 & r_1 & r_0 & \dots & r_{n-3} \\ . & . & . & r_0 & . \\ r_{n-1} & r_{n-2} & r_{n-3} & \dots & r_0 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ . \\ a_{n-1} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ . \\ 0 \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This is least-squares inverse filter that has the same form as the matrix equation (3**)**. Therefore, Wiener spiking deconvolution is mathematically identical to least-squares inverse filtering. The autocorrelation matrix on the left side of equation (**3**) is computed from the input seismogram and in the case of Wiener spiking deconvolution, whereas it is computed directly from the known source wavelet in the case of least-squares inverse filtering [6-8].

III.SIMULATIONS AND RESULTS

A sinusoidal signal of frequency of 500 Hz and duration of 1 second sampled at a rate of 44000 Hz is taken and inverse filter for de-spiking is designed using (3). Next, a composite signal consisting of three such delayed sinusoidal signals is designed. The delays of three signals are 2.18 ms, 6.54 ms and 28.3 ms. The composite signal is passed from the designed WSD filter. The length of the filter is 1/10 of the length of the signal. The output of the filter consists of three peaks as shown in Fig. 1. The similar experiments are conducted with square wave instead of sinusoidal wave and rest all the parameters are kept similar. The output of the filters is shown in Fig. 2.

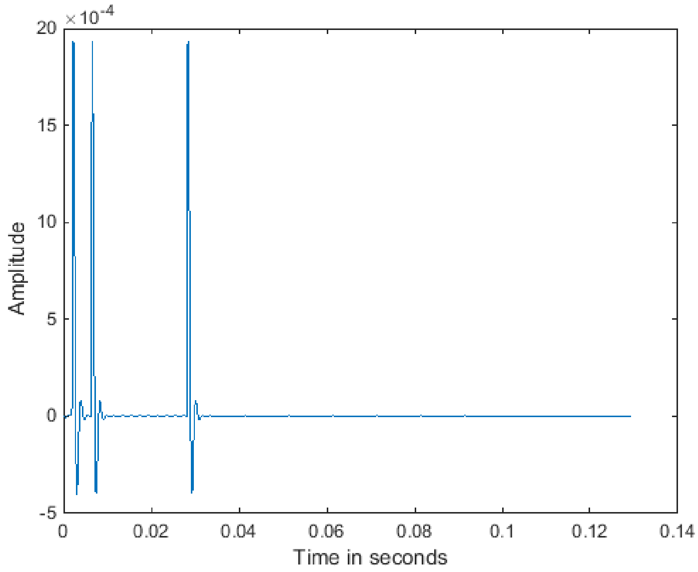

Fig. 1. WSD filter (1/10 length) output for the composite input signal.

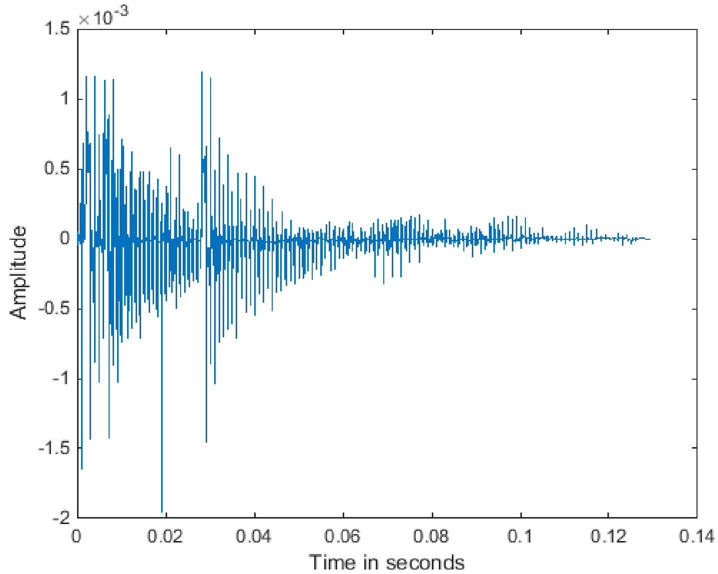

Fig. 2. WSD filter (1/10 length) output for the composite input signal (Square wave).

In the next experiment an MLS sequence of length 1 second instead of sinusoidal signal is taken. The MLS is generated using shift register length of 16 bits and first 44000 samples are taken to obtain 1 second signal. The outputs of the designed WSD filter for MLS sequence are shown in Fig. 3.

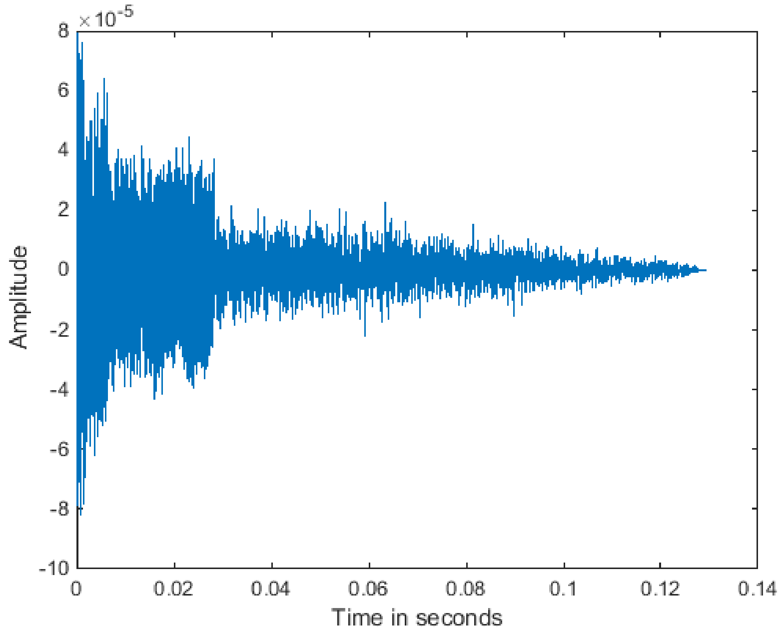

Fig. 3. WSD filter (1/10 length) output for the composite input signal (MLS).

A chirp signal with starting frequency of 100 Hz and ending frequency of 10 kHz and duration of 1 second sampled at a rate of 44000 Hz is taken and inverse filter for de-spiking is designed. Next, a composite signal consisting of two such delayed chirp signals is designed. The first delayed signal with a delay of 2.18 ms is the direct pickup and the second signal with a delay of 100 ms is the reflected signal from the bottom of the snow pack of 100 cm depth (assuming the speed of sound to be around 200 m/s). The output of the WSD filter gives two peaks as expected as shown in Fig. 4.

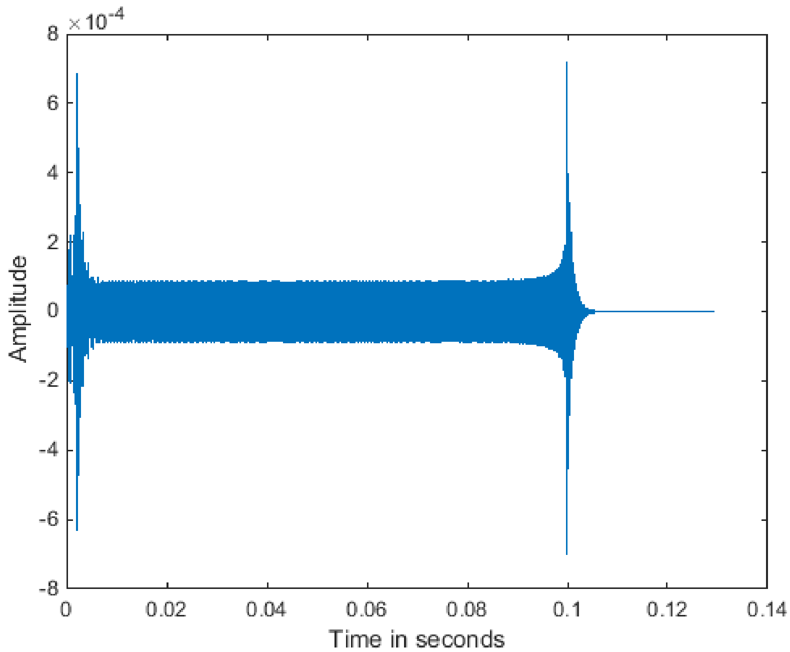

Fig. 4. WSD filter (1/10 length) output for the composite input signal (Chirp Signal).

Finally, the composite signal containing the two chirp signal (100 Hz-10000 Hz) is passed through the low pass filter. The second delayed chirp signal in composite signal also has frequency dependent attenuation. The attenuation constant values are taken to be linearly increasing from 0.05 dB/cm at 100 Hz to 0.3 dB/cm at 10 kHz. The output of the WSD filter is shown in Fig. 5. It is observed from Fig. 5 that there is a signature corresponding to greatly attenuated echo specially at higher frequencies.

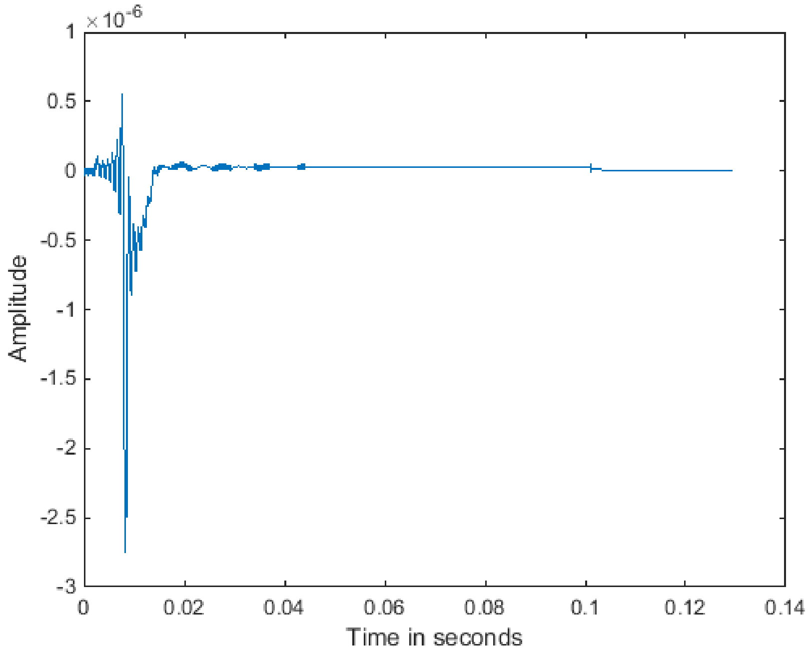

Fig. 5. WSD filter (1/10 length) output for the composite input signal (Chirp Signal)

IV.CONCLUSION

It is concluded from the simulations that sinusoidal and chirp signals are the best suited probe signals as these can be de-convolved in such a way to generate hyper sharp peaks in the time domain. The squares wave and MLS sequence do have not good property in terms of de-convolution filtering. The chirp waveform is also tested in the presence of frequency dependent attenuation. This signal is found to be robust even in the presence of frequency dependent attenuation and one is able to obtain the signature of the reflections as shown in last figure. Therefore, it can be concluded that chirp signal or linear frequency modulated waveform is the best probe waveform to be used in WSD filtering.

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