Seismic events detection using Cauchy-Schwarz inequality

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Abstract

Automatic detection of seismic reflection events is an important issue in processing of seismic data. Cauchy-Schwarz inequality is used to identify reflection events registered in seismograms. Knowing the limit values that inner product can take, it is possible to establish when a reflection is present in a seismic trace. The results of automatic detection were applied in obtaining semblance panel for a CMP gather. Results show that using detected reflection events, coherence measures for stacking velocity estimation are improved. The method can be applied in other stages of seismic data analysis and processing, especially in those where coherence measures are needed.

Introduction

Automatic detection of seismic events registered in seismograms has been an important subject in seismology and seismic data processing. In seismology, detection of seismic events has been treated together with the problem of phase identification (Nakamula et al, 2007; Bai and Kennett, 2000). Specific features can be detected in registered seismograms using suitable methods (Wang et al., 2002).

Several methods have been used for identifying seismic reflections in a seismogram but most of them are computational expensive. Wadsworth et al., (1953) and Key and Smithson (1990) dealt with the problem of detecting wave arrivals treating seismic trace from a probabilistic viewpoint, applying concepts of time series and eigenstructure of covariance matrices, respectively. These kinds of approximations have been also used tied to the influence of frequency in seismology studies (Moriya, 2009).

In this work, we propose to use Cauchy-Schwarz inequality for automatic detection of wave arrivals in a seismic dataset. Cauchy-Schwarz inequality establishes the extreme values that inner product can take, letting to know when a reflection is registered. Results are applied in obtaining NMO velocity semblance panel for CMP gathers corresponding to synthetic and field datasets. Time and velocity resolution are improved in coherence measurements showing that the method can be applied in other stages of seismic data processing.

Method

Cauchy-Schwarz inequality

Cauchy-Schwarz inequality is an important concept in digital signal processing. It is stated as in Callebaut (1965)

$$0 \le \left|\langle x, y\rangle\right| \le \|x\|_2 \, \|y\|_2 . \tag{1}$$

It establishes that the upper bound of the absolute value of the inner product between two signals, $x[n]$ and $y[n]$, where n is the time index, is the product of their l_2-norms and the lower bound is zero. In that way, inner product is a measure of the similarity between the signals involved.

Cauchy-Schwarz inequality was applied to identify seismic reflection events in a seismogram, acting as a matching filter. A reference wavelet was used as a pattern comparison in the seismogram. Equation (1) was then applied using the reference wavelet and a moving time-window of the same length throughout the seismic trace. Reflection events were detected when a high value was obtained for the normalized inner product between both signals.

Stacking velocity estimation

Normal moveout correction has been widely used in seismic data processing. It approximates geological media to a flat layered model composed by isotropic layers. Therefore, travel-time is a hyperbolic function of offset in a CMP gather,

$$t^2 = t_0^2 + \frac{x^2}{v^2}, \tag{2}$$

where, t_0 is the normal incidence travel-time and v is NMO velocity. Once NMO correction has been applied using several trial velocities, coherence operators can be used to obtain the most suitable velocity function for correction. Conventional semblance was defined as (Neidell and Taner, 1971):

$$S(t_0, v) = \frac{\sum_{j=t_0-N/2}^{t_0+N/2} \left| \sum_{i=1}^{M} X(j,i) \right|^2}{M \sum_{j=t_0-N/2}^{t_0+N/2} \sum_{i=1}^{M} \left| X(j,i) \right|^2} . \tag{3}$$

Coherence is measured in a time window of length N giving the semblance panel for a CMP gather, X, consisting of M traces.

Examples

An alternative form of the Cauchy-Schwarz inequality was used in this work:

$$-1 \leq \frac{\langle x, y \rangle}{\|x\|_2 \|y\|_2} \leq 1. \quad (4)$$

This normalized form let to takes into account extreme values, close to -1, when phases of reference wavelet and registered signal are opposite leading to high absolute values for the normalized inner product.

A threshold value can be applied to isolate individual arrivals. All values for the normalized inner product below threshold parameter are zeroed. Examples presented here used a value between 0.8 and 0.9.

The method described was applied to a synthetic seismic dataset. Figure 1 shows a velocity model elaborated for this purpose. Synthetic seismic data was obtained using ray tracing. A CMP gather was extracted from synthetic dataset (Figure 2a). It consists of 20 traces sampled at 4 ms. Maximum offset is 1425 m. Offset interval between traces is 100 m.

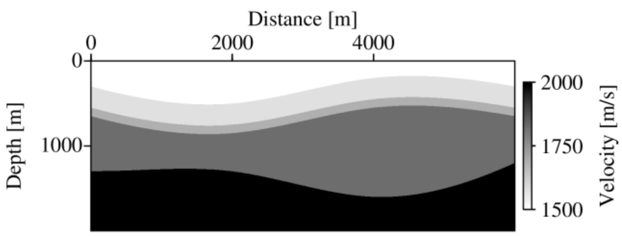

Figure 1: Velocity model used in modeling of synthetic seismic data.

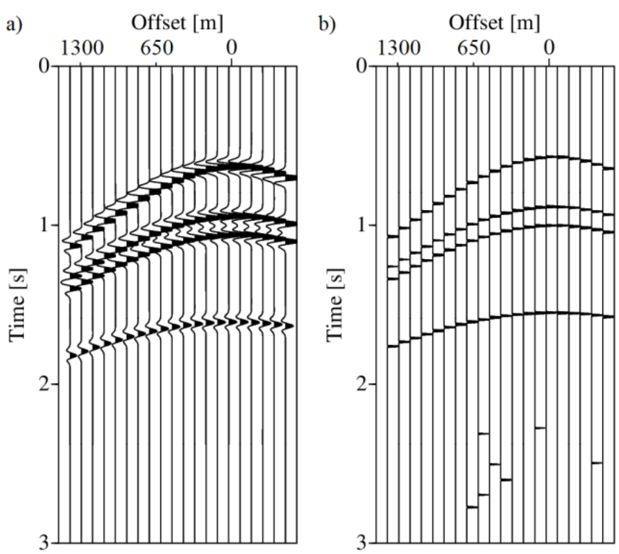

Figure 2: Synthetic CMP gather (a) and seismic reflections identified in the dataset (b).

First arrival registered in a trace was used as reference wavelet (Figure 3). It had 33 samples and defined the length of moving time window for applying the method.

Result of automatic detection is shown in Figure 2b. Registered reflections are effectively identified by the method. Some minor artifacts are produced due to some contributions at higher times.

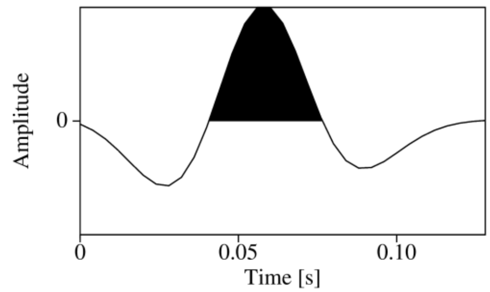

Figure 3: Reference wavelet used for the identification of seismic reflections in synthetic data showed in Figure 2a.

Results

Application to stacking-velocity estimation

Identified seismic reflections were used as entry for NMO velocity semblance calculation. Figure 4 shows a comparison between semblance panel obtained using original CMP gather (a) and the dataset corresponded to automatic detected events (b). Semblance obtained using the results of automatic detection clearly defines four reflection events and their corresponding stacking velocity, eliminating some interference artifacts present in semblance panel for the original CMP gather due to nearly close registration of reflectors and similar NMO velocity values.

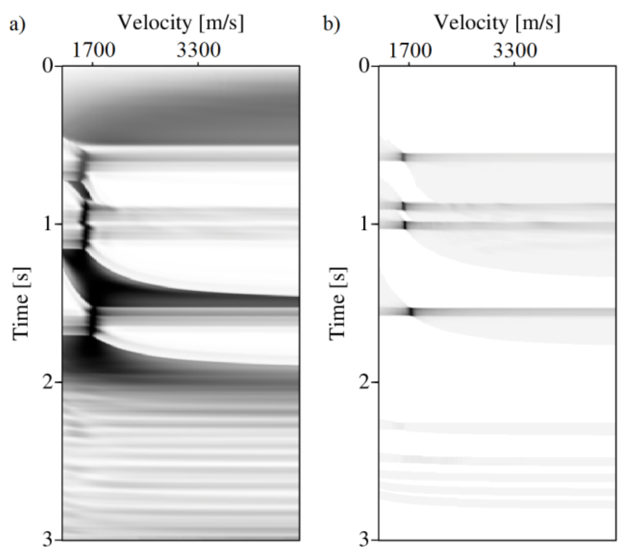

Figure 4: Conventional semblance panel obtained from original CMP gather (a) and the dataset of identified seismic reflections (b).

Field data example

A CMP-gather extracted from a 2D acquisition in Jequitinhonha Basin, Brazil, was used to evaluate the performance of the method. Dataset consists of 60 traces sampled at 4 ms. Maximum offset is 3720 m and offset interval between traces is 60 m. Preprocessing of dataset consists on amplitude correction and muting of samples above first reflection arrival (Figure 5a).

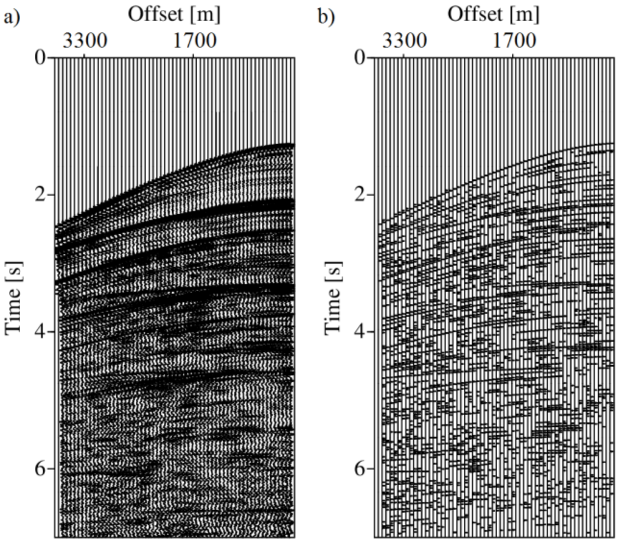

Figure 5: CMP gather from field data (a) and seismic reflections identified in the dataset (b).

Reference wavelet needed in the method was obtained in a similar way as for synthetic data. First reflection arrival was extracted from one trace (Figure 6). It consisted in a signal of 11 samples in length.

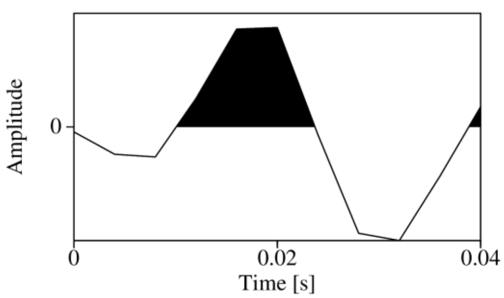

Figure 6: Reference wavelet used for the identification of seismic reflections in field data showed in Figure 5a.

Figure 7 shows the results of obtaining conventional semblance panels for the original CMP gather (a) and the set of arrivals detected using the method described above (b). Stacking velocity coherence resolution is improved when using the dataset of identified reflections as entry. Velocity function is more easily interpreted, especially for shallow reflectors.

Poor identification of seismic reflections at higher depths is attributed to distortion of source wavelet due to propagation. Attenuation and dispersion phenomenon affect wavelet form and, therefore, identification of registered events. Adaptive techniques for estimating reference wavelet could be applied to improve the performance of the method in deeper reflectors (Akram and Eaton, 2012).

NMO velocity analysis was performed using detected reflections in CMP gathers. Figure 8 shows the staked section that was obtained.

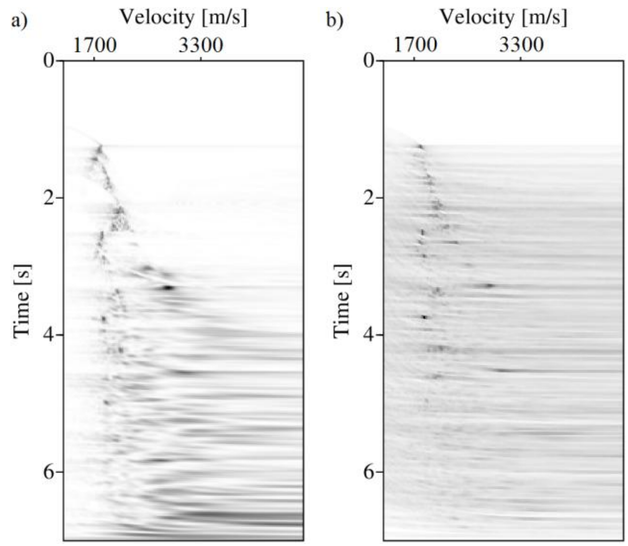

Figure 7: Conventional semblance panel obtained from original CMP gather (a) and the dataset of identified seismic reflections (b).

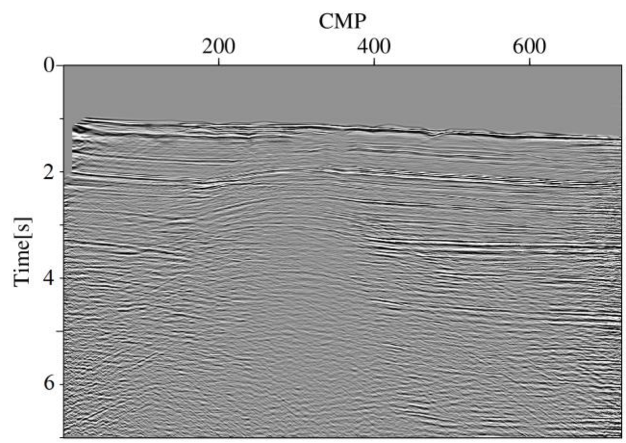

Figure 8: Stacked section obtained using NMO velocities obtained from reflections detected automatically.

Conclusions

Cauchy-Schwarz inequality was applied to identify reflection events registered in a seismogram. It operates a reference wavelet and a moving time window in the seismic trace. Detected seismic reflections were applied in obtaining conventional semblance panel for a CMP gather, improving time and velocity resolution for NMO velocity estimation. The results show that the method can be applied in obtaining other coherency measures in seismic data processing, e.g., migration velocity analysis.

Acknowledgments

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