SEMI-AUTOMATIC PICKING OF FIRST ARRIVALS THROUGH CROSS CORRELATION USING SPLINE INTERPOLATION APPLIED TO NEAR-SURFACE SEISMIC SURVEYS

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Abstract

Cross-correlation between adjacent seismic traces is one of several ways to estimate the time shift between first arrivals on seismograms. The accuracy of this method is limited to the sampling interval of the recorded seismic energy and the signal-to-noise ratio and uniformity of the seismic wavelet. For situations where the sampling interval is large interpolation between samples can be used to refine and improve results from this technique. Simple linear interpolation, however, preserves the position of the maximum-recorded data value of the wavelet. Such an approach may not provide an exact estimation for the peak value of the wavelet and is therefore susceptible to errors due to noise influence. A spline function fit to the peak-value samples will better define the position of the wavelet maximum and as a result the first-arrival shift estimations are more accurate. Furthermore, the relatively small number of samples used in the spline fitting process can act as a second round refining correction of the time-shift estimate, which is especially valuable when data are noisy. This algorithm reduces the error of first-arrival picking algorithms that use simple cross correlation.

Introduction

First-arrival picking algorithms can be divided into several types of methods, including the coherence method (Gelchinski and Shtivelman, 1983), cross-correlation method (Peraldi and Clement, 1972; Lanz et al., 1998), neural network method (Veezhinathan et al., 1991).

Coherence and neural network methods assume the existence of patterns in the first arrivals. Pattern recognition of this type is effective when a simple (layered) earth model can be used to approximate the earth structure. This simple earth-model scenario rarely matches the near-surface conditions when studied with the detail required of most modern surveys. Cross-correlation methods are considered to be most appropriate for the near-surface surveys since their algorithm is based on trace-by-trace evaluation of the first-arrival times.

The accuracy of cross-correlation methods is limited by the sampling interval of the data and consistency of the source wavelet. To overcome the sampling limitation Lanz et al. (1998) fitted a quadratic curve to the cross-correlation function. By doing this an additional component to the first arrival shift between traces can be estimated. Since this additional evaluation is controlled by the maximum of the cross-correlation function the maximum value resulting from this additional evaluation is smaller than one sampling interval. We propose a cross-correlation function method in which the additional evaluation may be greater than one sampling interval.

This new proposed cross-correlation method is not fully automatic because of the need to select a starting point of the first-arrival wavelet of the first trace from a certain range of traces. Techniques, such as the MER (moving average ratio) to estimate the beginning of first arrivals can be used but these techniques perform poorly when the signal-to-noise ratio is low (Spagnolini, 1991). In practice, this is most often the case when different types of noise affect the first arrival picking algorithms. The cross-correlation approach to first-arrival picking assumes that the phase and shape of the first arrival wavelet are constant from trace to trace. In reality, the phase and shape of the first-arrival wavelet vary for different parts of the shot gathers. The main reason for this distortion is that the earth acts as a minimum-phase low-pass filter (Aki and Richards, 1980). Noise can be another source of wavelet-shape alteration. Manual adjustment of the actual first-arrival time is necessary from time to time to account for the inconsistent shape of the first arrival wavelet and the lack of a consistent pattern in the first-arrival times from trace to trace, which is typical for many near-surface settings.

The goal of this work is to demonstrate a method for first-arrival picking that takes into consideration the wavelet shape inconsistency, lack of first arrival patterns from trace to trace, and the presence of noise.

The Method

Key to the effectiveness of this method is the manual selection of the first-arrival on the initial trace after which the form of the first arrival wavelet is traced. Cross-correlation focusing on the maximum amplitude of the seismic wavelet is the more reliable approach because the maximum amplitude (regardless of the wavelet phase) is usually the most pronounced and easily detectable energy. A wavelet window is centered on this maximum. This wavelet window is cross-correlated with the second trace (Trace2) within a search window, which is defined by the maximum expected time shift, a criteria specific to a particular data set. The maximum of the cross-correlation function is used to estimate the first-arrival shift samples (Figure 1).

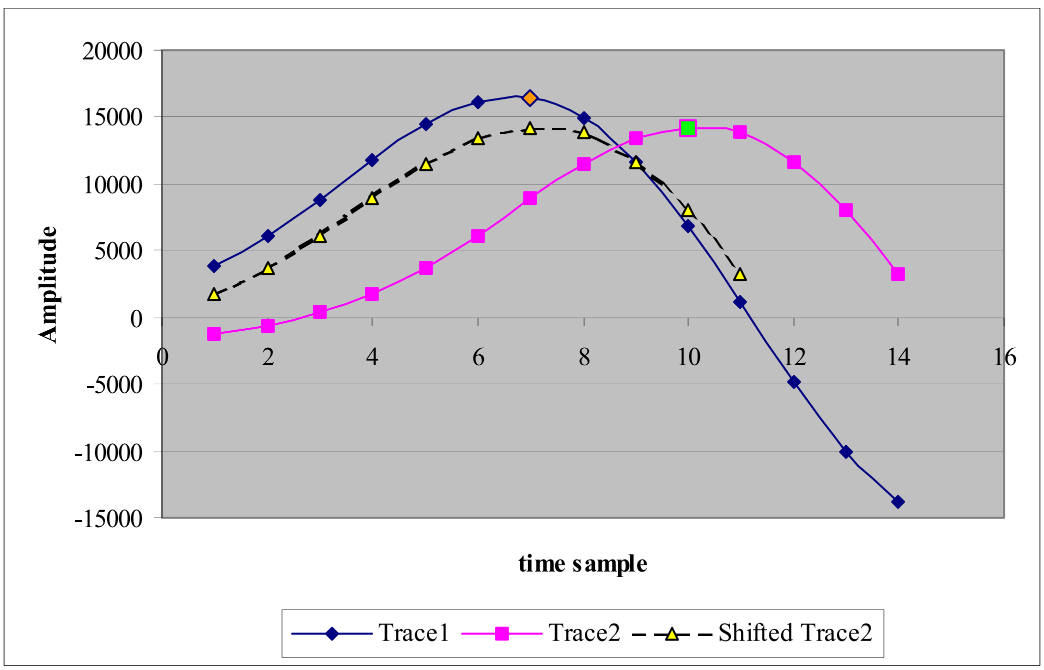

Figure 1: First arrival cross-correlation between Trace1 (diamonds) and Trace2 (squares). The cross-correlation function has a maximum when Trace2 is shifted (to the left) by 3 samples into the Shifted Trace2 curve (dashed triangles).

Additional estimation of the sub-sampling interval shift is performed on each trace by fitting a spline function to the samples (for example 5) on either side of the starting-trace wavelet peak (Trace1). The first-arrival shift obtained in this fashion is then used to find the sample on the following trace, which best fits a spline function. Then the exact times of the spline maximums are used to calculate an additional sub-sample time shift between the two traces (Figure 2). Since the spline maximum on each trace can be almost one sample shift away from the cross-correlation maximum sample the total sub-sample time shift can be greater than one sample interval. Such a scenario is commonly encountered when significant wavelet-phase distortions occur from one trace to another.

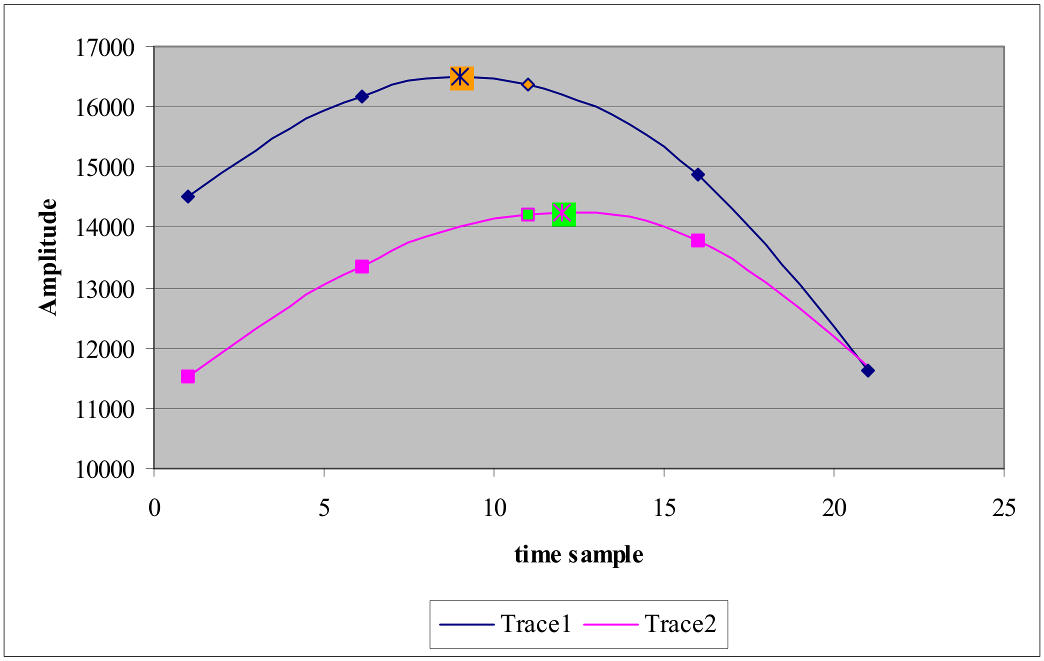

Figure 2: Spline-fit maximum values of Trace1 (diamonds) and Trace2 (squares). The squares and diamonds indicate the original sample values. The stars indicate the location of the maximums of the fitted spline functions.

This combined cross-correlation and spline-fitting method behaves well in the presence of noise. The number of samples used to fit the spline function (for example 5) form a second window in which the time shift is reevaluated, excluding possible noise outside that window. For example, noisy data can cause the cross-correlation function to make inaccurate sample-shift estimate (Figure 3). The second pass of estimation using the minimum of samples (5 in this example) necessary to fit the spline function reevaluated and estimated an additional time correction of approximately 1.5 samples (Figure 4). Noise that affected the cross-correlation shift beyond the spline samples was excluded during the second round of estimation.

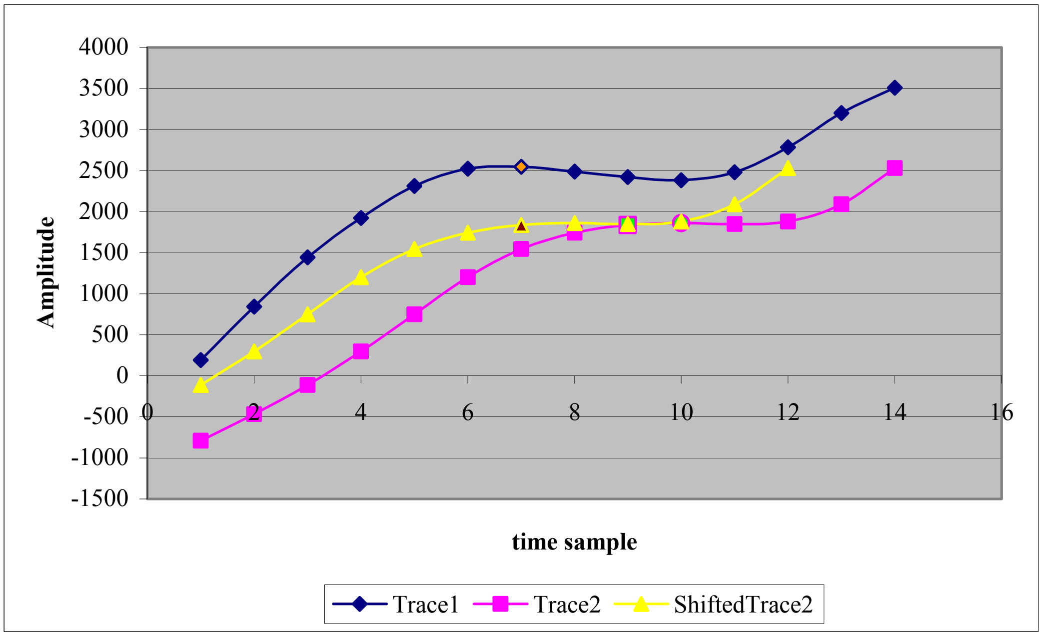

Figure 3: Noisy data between time samples 9 and 14 influence the cross-correlation function to have a maximum when the second trace is shifted by 2 samples instead of 3 samples.

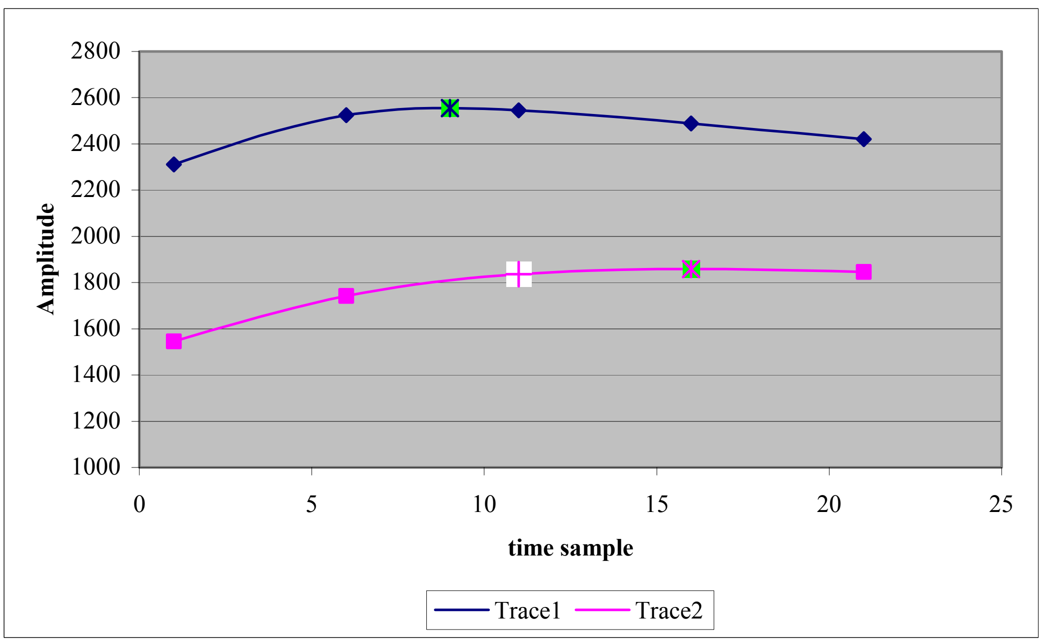

Figure 4: Reevaluated positioning of the maximum peak of the wavelet (from the cross to the star) of Trace2 after using a small spline-fitting window (5 samples) and ignoring data influenced by noise outside that window.

Data Example

The following is seismic data that was collected in the Sonora Desert, Arizona, USA. The seismic wavefield was collected using a fixed spread of 240 receiver stations spaced at 1.2 m. A Rubber-band Assisted Weight Drop (RAWD) was used for the source (50 kg mass accelerated ½ m and impacting striker plate of equal mass). It provided a repeatable broad bandwidth and high-energy pulse with a minimum-phase waveform. Data were recorded from a fixed-spread using 10 Hz geophones and a 240-channel Geometrics Strata View seismograph. A source spacing of 4.8 m inline and 1.2 m offline maximized redundancy and economics. Noisy seismic data from the shot records at the beginning of the spread are displayed on Figures 5 and 6.

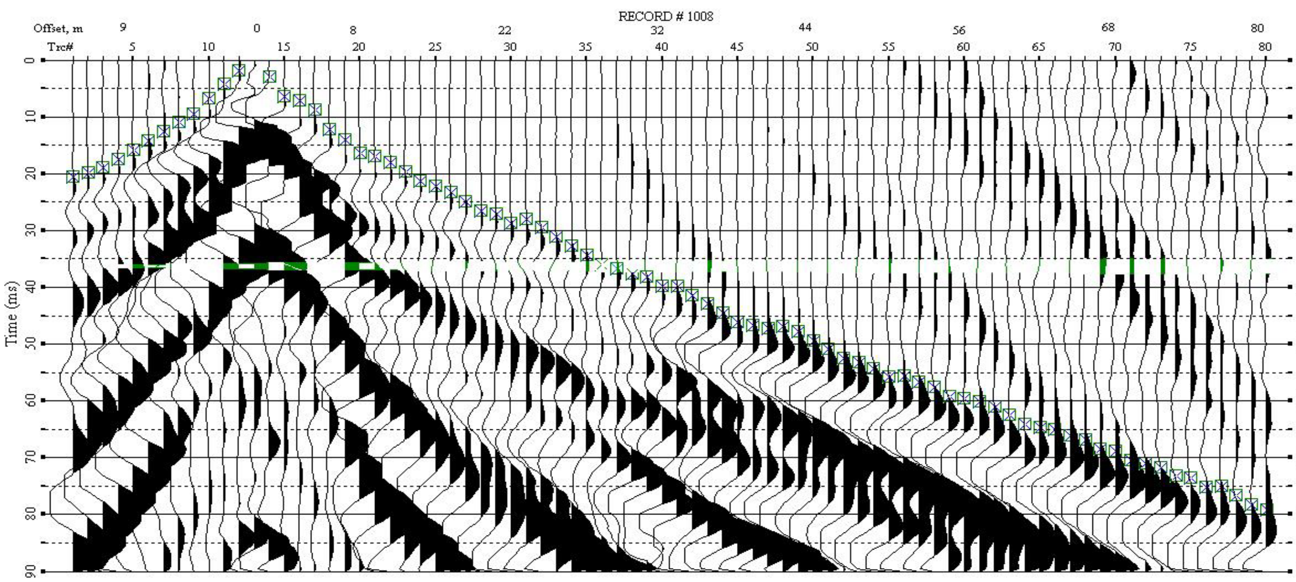

Figure 5: Semi-automatic first arrivals picking of noisy seismic data from the Sonora Desert, Arizona, USA.

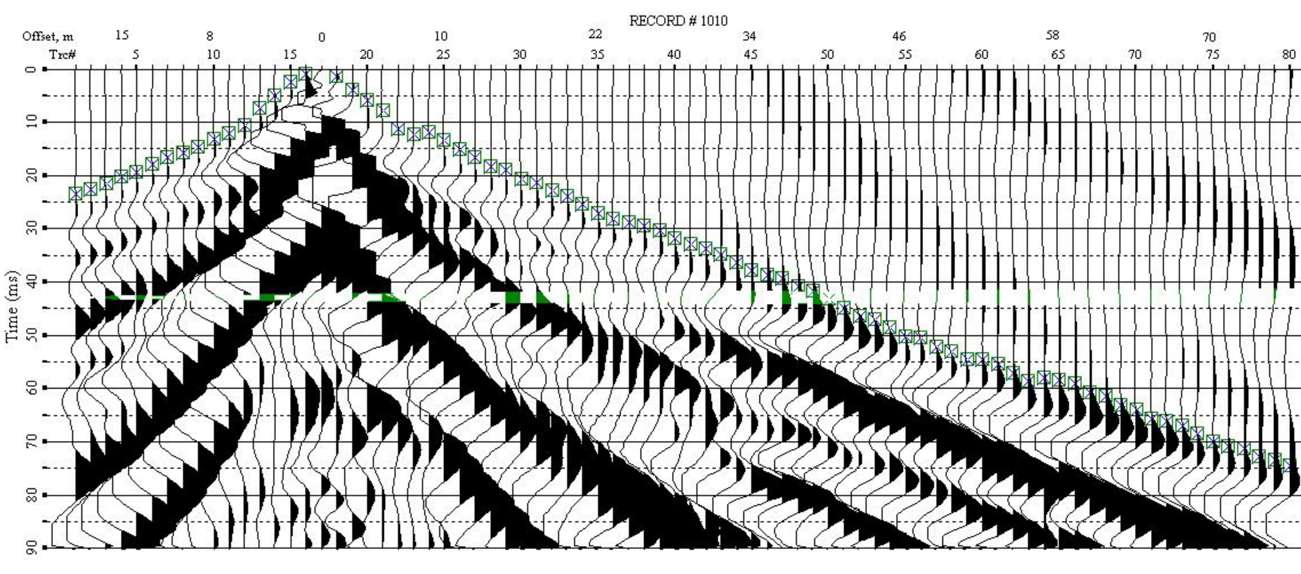

Figure 6: Semi-automatic first arrivals picking of noisy seismic data from the Sonora Desert, Arizona, USA.

Only three swaths of ranges were used to automatically pick the first arrivals beyond the several traces near the source (Figure 5), traces 19-39, traces 40-80, and an additional correction for the phase start was necessary for traces 58-62. Only two swaths of ranges were used to automatically pick the first arrivals beyond the several traces near the source (Figure 6), traces 24-63, traces 64-80. The above example demonstrates the high level of efficiency of the proposed first-arrival-picking algorithm in the presence of noise.

Conclusions

None of the available first arrivals picking algorithms perform well in the presence of noise. Attempts to use pattern recognition techniques are rarely applicable to highly variable near-surface conditions.

The proposed method for first arrival picking has two advantages. It accurately calculates the time distance between the first arrival peaks of consecutive traces, and it also reevaluates the first arrival picking by using a smaller, refined window thus reducing the influence of noise.

By emphasizing the cross-correlation of the maximum amplitude of the seismic wavelet the proposed algorithm assumes constant time-distance between the beginning and the peak of the first-arrival wavelets. If this time-distance varies from trace to trace it is up to the user to decide if such a change is due to noise, in which case such changes can be ignored (e.g. as at offsets larger than 55 m in Figure 6) or if such a change is due to earth response, in which case the changes need to be accounted for. Currently, manual intervention is required to adjust for inconsistencies between the beginning and the peak of the first-arrival wavelets in the case of the earth influenced changes in the distance from making amplitude and onset of the signal. In practice, such interventions are rarely necessary, making the algorithm very efficient. Controlling concepts of this algorithm can be used as building blocks and combined with other techniques for creating fully automated first-arrival-picking algorithms.

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