A NEW AUTOMATIC FIRST BREAK PICKING METHOD BASED ON THE STA/LTA FRACTAL DIMENSION ALGORITHM

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ABSTRACT

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This paper describes a new approach to seismic first break picking based on comparing short-time averages (STA) with long-time averages (LTA) of transformed amplitudes and consideration the fractal dimension variations along the seismic traces. Reliable and accurate detection of first breaks is a key step for the determination of seismic parameters. The results of tests show that this method is quite reliable and is less susceptible to false-positive detection errors. Also by this approach, the result is an improvement in total picks, accuracy, and consistency. A small range of thresholds can be used for a wide range of seismic signals with different noise levels. This suggests adaptive STA/LTA fractal dimension may be less sensitive to analyst parameter choices than other methods. The proposed algorithm was verified using seismic traces and synthesized seismic traces with different noise levels. Also, the STA/LTA and STA/LTA fractal dimension algorithms are performed on a shot gather acquired in a seismic project in the west of Iran. The results emphasize that the proposed approach is quite practical and reliable for noisy and bad seismic traces. Also, this algorithm is computationally efficient and easy to apply.

KEY WORDS: STA/LTA, fractal dimension, first break, seismic trace.

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INTRODUCTION

One of the important goals of seismic data processing is to determine an accurate time of the first arrival. In seismic data processing, first-break picking (FBP) is a critical step to provide first breaks for travel time tomography. FBP is the task of determining, given a set of seismic traces, the onsets of the first signal arrivals as accurately as possible. In general, these arrivals are associated with the energy of refracted waves at the base of the weathering layer or to the direct wave that travels from the source to the receiver (Sabbione and Velis, 2010). To calculate the static correction, which is a fundamental stage of data processing, the determination of the first arrivals is needed. So, the accuracy of the calculations is very important. Also, the quality of static correction for reflection and refraction methods depends on the reliability of first break picking (Yilmaz, 2001, P. 374). On the other hand, the manual picking method (first break determination carried out by visual inspection of fluctuations in the waveform) can be useful. However, when the number of channels in seismic acquisition increased, manual picking consumed more time and money, and an automated and effective first-break picking method became necessary. Also, some applications such as near-surface tomographic statics corrections (tomostatics) require a precise and rapid automated FBP method. Generally, first break picking quality is associated with the base of the weathering layer, near-surface structure, source type, and signal to noise ratio (S/N). As a consequence, the automated picking of first breaks can be a very difficult task if data are acquired in complex near-surface scenarios if the S/N is low (Sabbione and Velis, 2010). Several automated first-break picking methods have been proposed and applied in the last few decades. Peraldi and Clement (1972), introduced a method that was based on the cross-correlation of adjacent traces to find the delay time between first breaks and Hatherly (1982) proposed some complicated statistical tests that marked the first arrivals in seismic signals. A technique was developed by Gelchinsky and Shtivelman (1983) based on a combination of the correlation properties of the signal and statistical criterion. Coppens (1985) suggests a first-break picking method based on the energy that works well for areas with a high signal-to-noise ratio. Also, the location of the first breaks as a first approximation based on the detection of abrupt changes in the energy was developed by Spagnolini (1991).

Uncommon approaches include relatively new algorithms such as those based on neural networks. These approaches can be very useful for determining the first breaks (Murat and Rudman, 1992). Other uncommon approaches consist of the use of higher-order statistics (Yung and Ikell, 1997), variation in fractal dimension along the seismic traces (Boschetti et al., 1996; Jiao and Moon, 2000), and a method based on the wavelet transform (Tibuleac et al., 2003). Also, some improvements for the Coppens and fractal dimension-based methods have been proposed by

Sabbione and Velis (2013). Nevertheless, these approaches tend to fail when there are traces of heavy noise and poor quality. In this article, I proposed a new automatic algorithm to the first break picking based on comparing the short-time averages (STA) with long-time averages (LTA) of transformed amplitudes by taking into account the fractal dimension variation along the seismic traces. The STA/LTA is a reliable method for picking the first arrivals of P-phases in seismology. On the other hand, according to the fractal theory (Mandelbrot, 1983), the fractal dimension can quantify the partial geometric shape characteristic of seismic waveforms (Zhang et al., 2018). In this approach, the STA/LTA ratio can identify the first breaks by monitoring the rapid changes of the signal amplitude. Also, if a seismic waveform has a transition from background noise to signal plus noise, the change of geometric shape characteristics occurring in the transition can reflect the change of signal characteristics. Hence the fractal dimension can be used to detect the first break in seismic signals (Zhang et al., 2018). In this work, I introduced an adaptive STA/LTA for seismic exploration data by considering the fractal dimension.

STA/LTA FRACTAL DIMENSION ALGORITHM

In the proposed algorithm, the first break picking is based on the comparison between short-time averages (STA) and long-time averages (LTA) of transformed amplitudes and consideration of the rapid changes in fractal dimension along the seismic traces. The basis of this approach follows the STA/LTA algorithm in seismology. Indeed, the aim of the adaptive STA/LTA fractal dimension algorithm is to distinguish the first breaks in background noises.

For calculating the STA/LTA ratio, I consider two-time windows with different lengths. One of them is long and the other one is a short time window. Fig. 1 shows the two-time windows on a seismic trace. These two-time windows move on signals together, such that the short window is at the end of the long window. For this purpose, I calculate the summation of absolute amplitudes of the seismic trace within the two mentioned windows along the seismic trace [eq. (1)].

$$A_S = \sum_{i=t-s_l+1}^{t}(y_i + |y_i - y_{i-1}|)^2, \quad A_L = \sum_{i=t-L_l+1}^{t}\left(y_i + e^{-i\Delta t}|y_i - y_{i-1}|\right)^2 \quad , \qquad (1)$$

where S_l is the length of the short time window, L_l is the length of the long time window, Δt is the sampling interval of the data, and y_i are the amplitudes of seismic data. The length of both windows is fixed along the time series. Then I calculate the average amplitude in both windows to find out the STA/LTA ratio [eq. (2)].

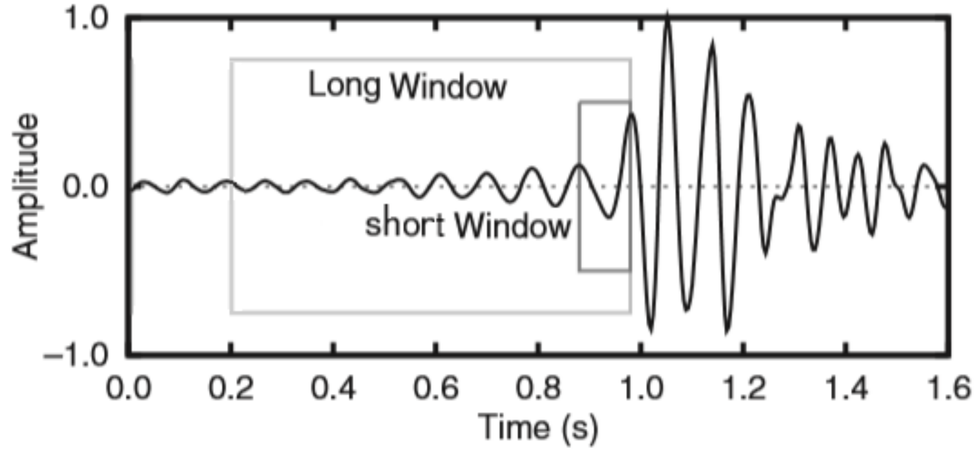

Fig. 1. Moving short and long time windows on seismic trace to calculate the STA and LTA.

$$\left(\frac{STA}{LTA}\right)_{Ratio} = \frac{\frac{1}{N}\sum_{i=t-s_l+1}^{t}(y_i+|y_i-y_{i-1}|)^2}{\left(\frac{1}{M}\sum_{i=t-L_l+1}^{t}\left(y_i+e^{-i\Delta t}|y_i-y_{i-1}|\right)^2+\varepsilon\right)} \quad , \tag{2}$$

where N and M are the numbers of samples in short and long time windows and ε is a stabilization constant that helps reduce the rapid fluctuations of the STA/LTA ratio that might lead to false results. This attribute is assigned to the last sample of the window. Since these windows move together with time, the STA/LTA ratio is calculated for every time sample.

Once the STA/LTA ratio exceeds a predetermined value, it indicates a significant break in data. A threshold is determined so that when the STA/LTA ratio goes above it, the algorithm has defined the first break of the seismic trace. The value of this threshold is important since the selection of the first breaks by the algorithm depends on the chosen threshold. This value determines by the operator by considering the signal-to-noise ratio at the first stage of the procedure. In addition, the lengths of short and long time windows (S_l, L_l) are calculated automatically which is based on fractal dimension changes [see eq. (5)]. Also, to enhance the performance of the first break picking method and overcome the problem of working with noisy seismic signals, the fractal dimension variation along the seismic waveforms has been considered. The fractal dimension has been used with STA/LTA to improve the accuracy and precision of the first break picking algorithm. In this approach, the divider method (Mandelbrot and Pignoni, 1983) has been used to calculate the fractal dimension. The basic implementation of this method is for a vibration curve. A straight line segment with "step size *r*" is selected to measure the curve from the start to the end. By completing this process, the number of measurements is recorded with the step size *N*, and the length of the vibration curve equals the product of *N* and *r* approximately. Fig. 2a shows four step sizes (r1, r2, r3, and r4) to calculate the length of the signal (*L*) for the fractal dimension measure in the first step. By considering a series of step sizes r_i, the corresponding N_i can be obtained, and the lengths can be calculated approximately by eq. (3).

$$L_i = r_i \times N_i \quad . \tag{3}$$

By decreasing the step size, the straight line segments can follow the curve more closely, and the calculated length of the vibration curve increases. A series of r_i and L_i is determined and a Mandelbrot-Richardson (M-R) plot can be obtained (see Fig. 2b). The fractal dimension (D) can be measured from the slope of M-R plot (S) as shown in eq. (4). Previous studies (Boschetti et al., 1996) showed that within a reasonable range of step sizes, this plot is an approximate straight line.

$$D = 1 - S \quad . \tag{4}$$

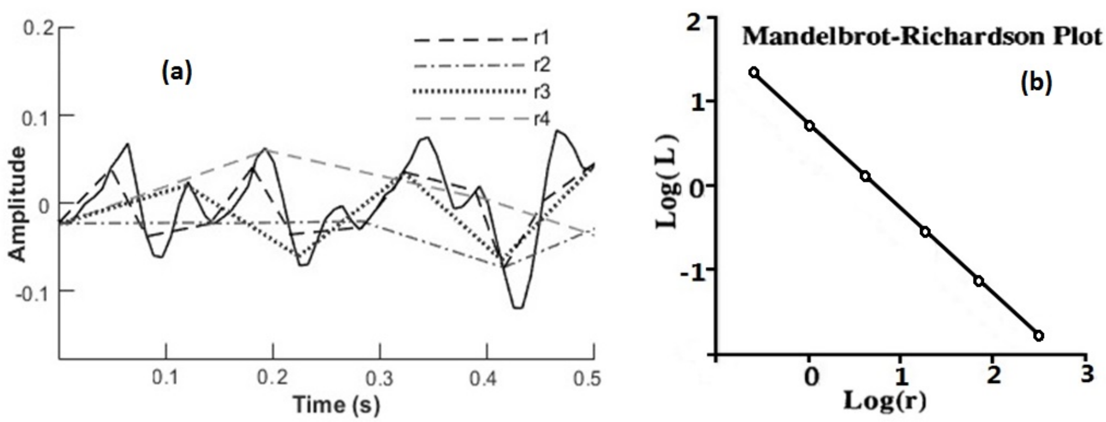

Fig. 2. a) The sketch displays how to calculate the length of a signal using step sizes (ri) based on the divider method. b) A Mandelbrot-Richardson plot, which is obtained by plotting the logarithm of the signal length versus the logarithm of the corresponding step size.

To calculate the fractal dimension of a seismic trace, similar to the last section, a moving time window is used to scan the trace from the start to the end along the time axis, as shown in Fig. 3a. While moving the time window, the fractal dimension of the waveform in each window is calculated and recorded at the corresponding time *t* (Fig. 3b).

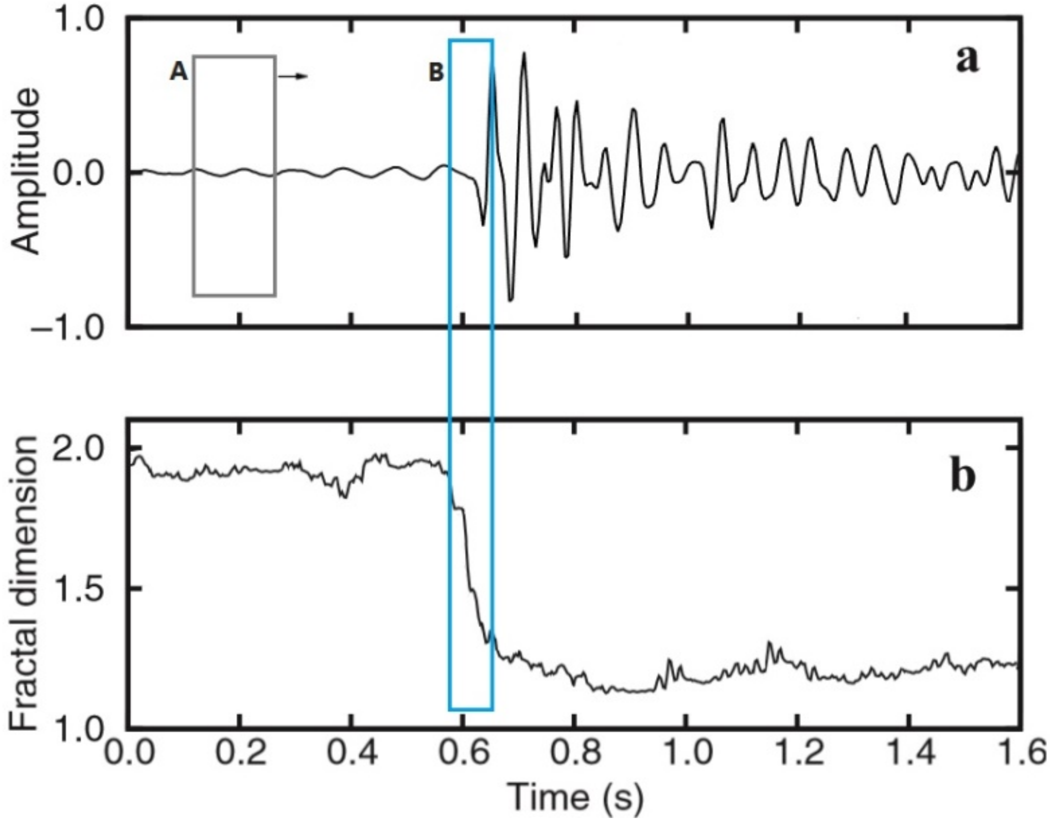

Fig. 3. a) A is a moving time window along the seismic trace which is used in the calculation of the fractal dimension. b) Fractal dimension of the seismic trace (in a). The blue window shows the jumping section in fractal dimension.

As shown in Fig. 3b, the calculated fractal dimension jumps in the section highlighted by the blue window. I name this the jumping section. The first break is located in this section and the time of the first break is determined from the jumping section.

To enhance the performance of the first break picking method, I used both STA/LTA and fractal dimension methods together in the proposed algorithm. Also, to save data processing time, and increase the accuracy of the first break picking, initially the fractal dimension of the seismic signal and then the jumping section are calculated. After this procedure, the STA/LTA ratio is calculated from the first to the end of the jumping section. For this process, the start and end times of the jumping section (t_A and t_B) were determined automatically, and accordingly, the lengths of the time windows (STA and LTA) were chosen as follows:

$$S_l = t_B - t_A \, , L_l = 10 \times S_l \quad . \tag{5}$$

So, the STA/LTA ratio calculations started at the t_S which is chosen as follows:

$$t_s = t_A - L_l \quad . \tag{6}$$

According to the proposed algorithm, if the STA/LTA ratio in the jumping section goes above the predetermined value, it represents the instantaneous change of the seismic trace. At this point of the time axis, the first break is identified in the seismic trace. Fig. 4 shows the STA/LTA fractal dimension algorithm.

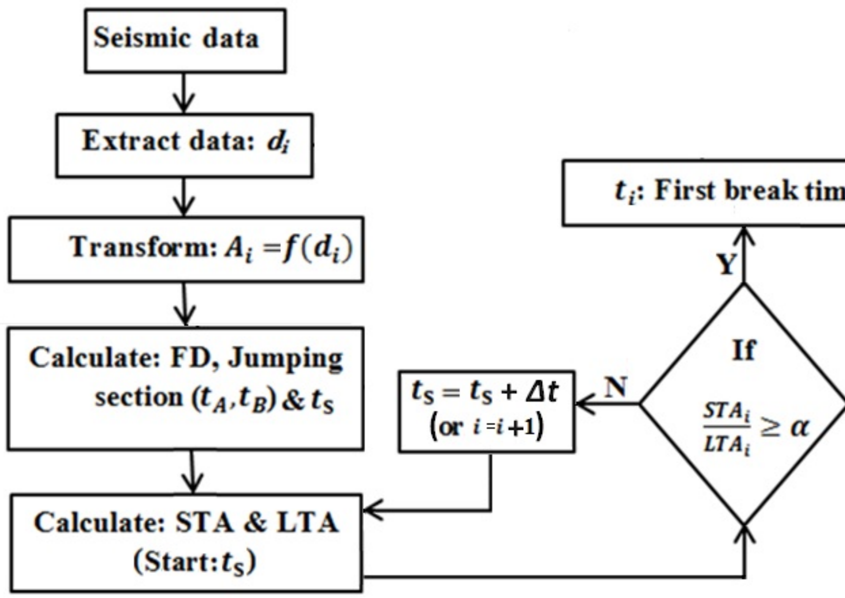

Fig. 4. The STA/LTA fractal dimension algorithm.

Verification of the STA/LTA Fractal Dimension Algorithm

To investigate the performance of my algorithm for detecting first breaks in seismic traces, a shot gather with 320 traces (250 Hz sample rate) was chosen which is obtained from a seismic project in the west of Iran. The first breaks of these traces were detected using STA/LTA fractal dimension algorithm, which is used as a reference. This approach was selected to determine the first breaks due to its simplicity, fast speed, and high accuracy. Initially, I performed my method on a single trace, to investigate the features and details of the results. Fig. 5 displayed the picking result, the STA and LTA, the STA/LTA ratio, and the calculated fractal dimension for a seismic trace. As shown in Fig. 5 the first break is picked when the STA/LTA ratio goes above the predetermined value (α=2.35) in the jumping section.

As mentioned earlier, this value is determined by the operator. This parameter is set based on the period and amplitude of the first arrival waveforms from a certain trace of a shot gather, which is easily determined by visual inspection. Here, to determine it, the exact location of the first arrival is determined by visual inspection of a seismic signal. Then the STA and LTA are calculated for this location, and the STA / LTA ratio is assumed to be α.

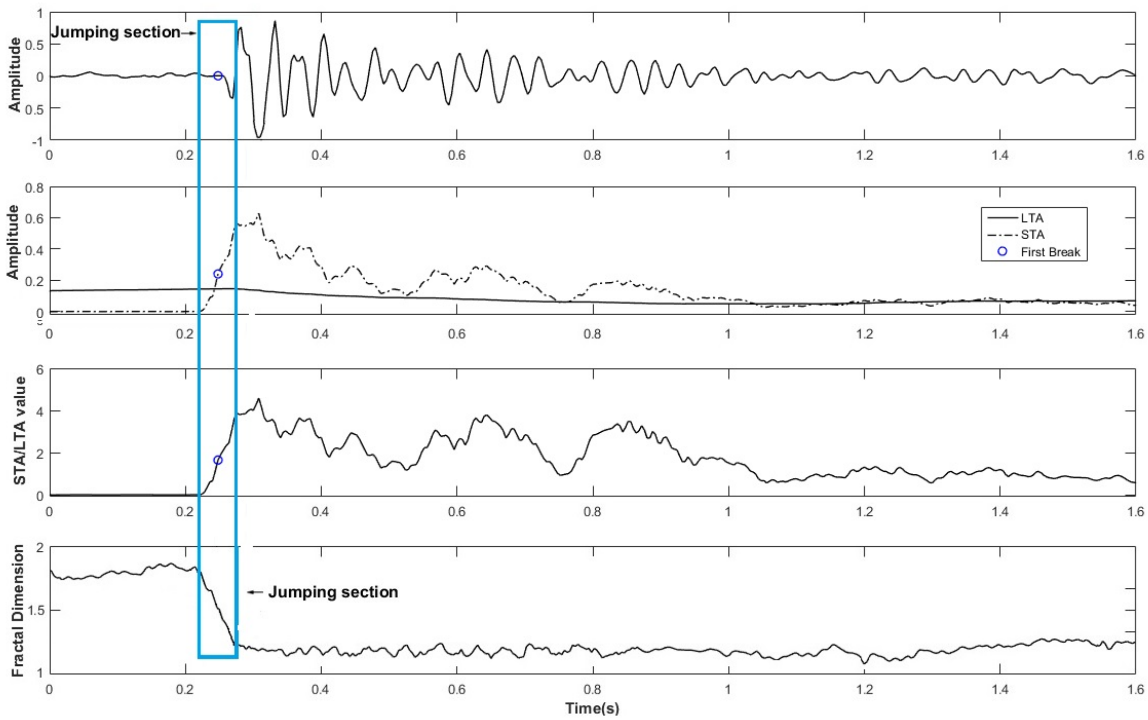

Fig. 5. The first break picking, the STA and LTA, the STA/LTA ratio, and calculated fractal dimension for a seismic trace.

Furthermore, to show the accuracy of the STA/LTA fractal dimension algorithm, I added different levels of noise to the seismic trace, and then first break detected by the STA/LTA fractal dimension algorithm. In this procedure, Gaussian white noise was added to real seismic traces and the synthesized traces were produced. Also, the signal level (SL, dimensionless) of the synthesized traces is defined as shown in eq. (7):

$$SL = 10 \times \log\left(\frac{SP}{NP}\right) \quad , \tag{7}$$

where *SP* is the power of the seismic signal and *NP* is the power of the noise. The *SP* can be calculated using eq. (8):

$$SP = \frac{\sum_{i=1}^{L_s} |S(i)|^2}{L_s} \quad , \tag{8}$$

where *S* is the seismic signal, and L_s is the length of the seismic signal. For a given signal level (SL), noise power (*NP*) can be calculated by eq. (7). So, the Gaussian white noise can be generated by MATLAB function AWGN and added to the seismic record to produce a synthesized seismic trace.

In this article, three sets of synthesized traces with signal levels =30, 20, and 10 were constructed, respectively, as shown in Fig. 6. The comparisons of detection accuracy were performed by the STA/ LTA fractal dimension algorithms on synthesized traces. Fig. 7 shows the results of the first break picking method on synthesized traces. The results show that my first break picking algorithm is quite reliable and efficient.

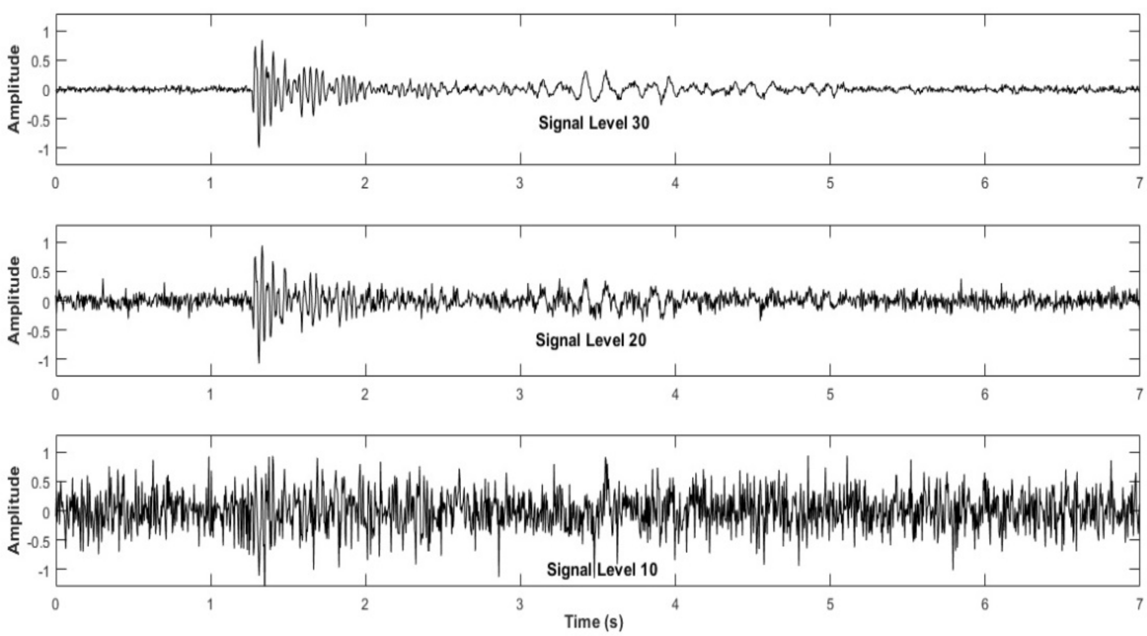

Fig. 6. The synthesized traces with signal levels = 30, 20, and 10.

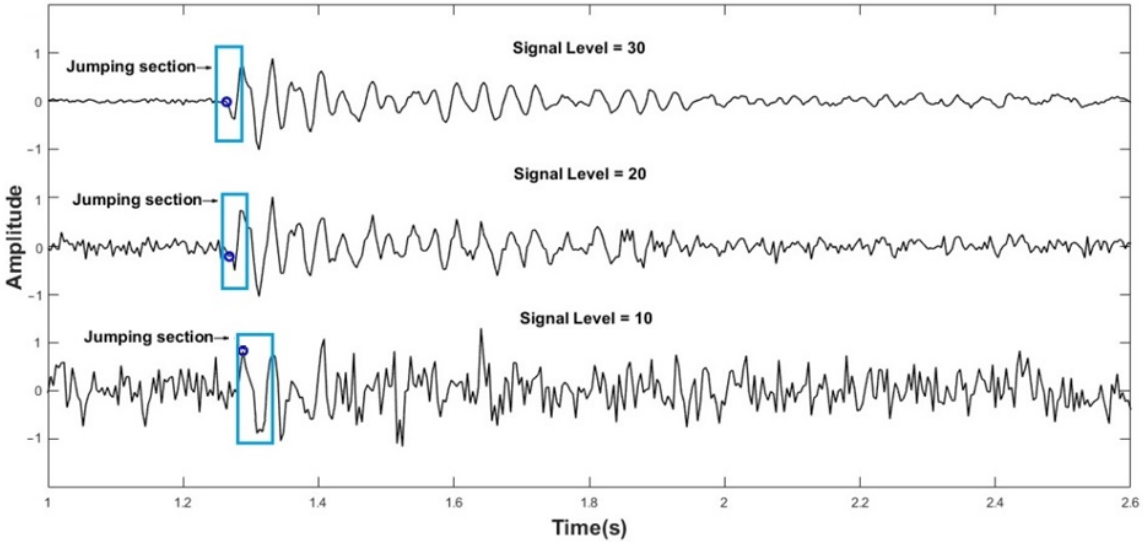

Fig. 7. The results of the first break picking method on synthesized traces with signal levels = 30, 20, and 10.

Testing the STA/LTA fractal dimension on a field data

In this section, the performance of the STA/LTA fractal dimension algorithm has been illustrated on a seismic dynamite field record that was acquired in the west of Iran. The seismic data obtained from this region does not have good quality due to the existence of the Gachsaran Formation (a high-velocity formation) and the geological complexities of Zagros. So, the signal-to-noise ratio for these data generally is low and can be used to investigate the performance of the proposed method. The data that has been chosen is a shot gather with 320 traces and high background noise level. The sampling interval of this data is 4 milliseconds. Fig. 8 shows the results of the first breaks picked by the STA/LTA fractal dimension algorithm (blue) and STA/LTA algorithm (red). Also, to display more details, the first 50 traces and the part-time of the shot gather were chosen (see Fig. 9).

As shown in Figs. 8 and 9, the results for applying the STA / LTA fractal algorithm (blue) are better than STA/LTA algorithm (red). Indeed, determining the first receipt in the jump section (between t_A and t_B, calculated from fractal dimension changes) is faster and more accurate than searching the entire seismic signal. On the other hand, by applying the STA/LTA algorithm without considering the fractal dimension changes, the possibility of accurately determining the first arrivals reduced in signals with a low signal-to-noise ratio. Also, the results show that my proposed algorithm performed well in determining the first breaks and is quite reliable.

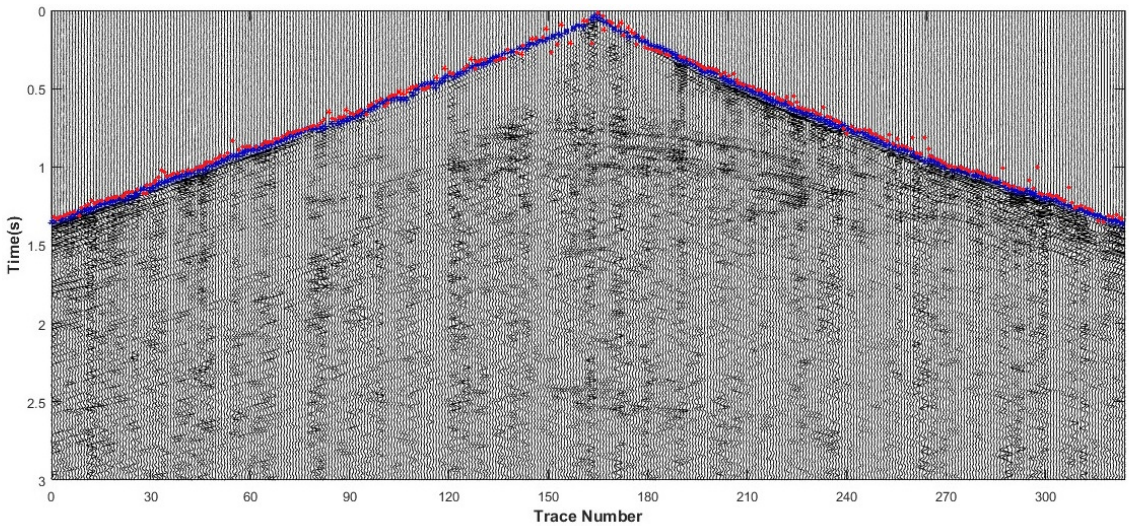

Fig. 8. The results of the first break picking on a shot gather (obtained from a seismic project in the west of Iran) by the STA/LTA fractal dimension algorithm (blue), and STA/LTA algorithm (red).

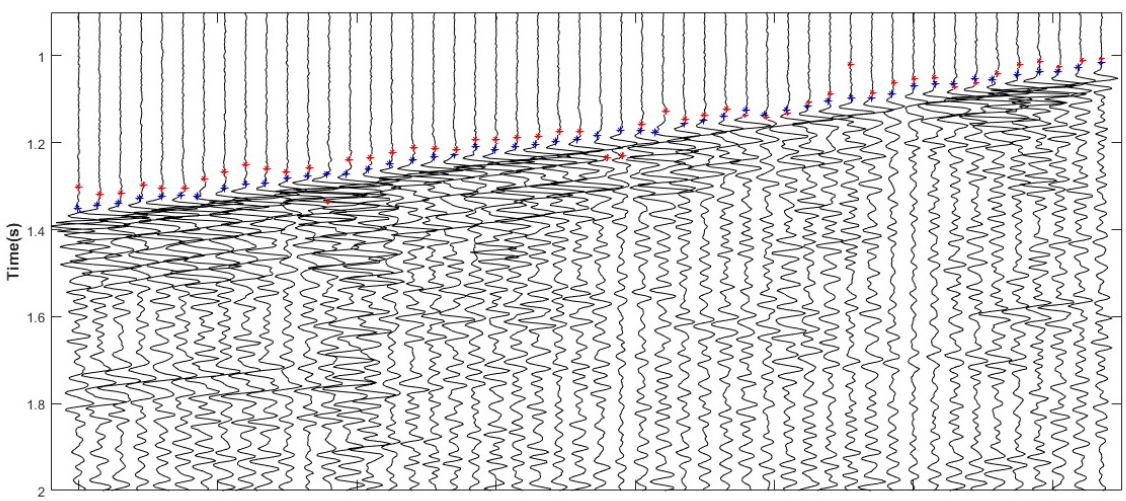

Fig. 9. The results of the first break picking for the first 50 traces of the previous shot gather.

DISCUSSION

The STA/LTA fractal dimension algorithm requires a large amount of calculation. The calculation of fractal dimension variations requires the measurement of the length of the seismic trace within the window for different step lengths and then regression of the points so obtained. These calculations must be performed for the start to the end of the seismic trace. Also, an exceed calculation is required to determine the jumping section. After this procedure, STA/LTA ratio must be calculated in the jumping section. The implementation of this algorithm is quite straightforward, but the speed of code and the accuracy of first break picking, depend on a different number of parameters. However, by determining the jumping section and calculation the STA/LTA ratio in this section, valuable time would not be spent investigating useless areas. The speed process and accuracy of the results depend strongly on the signal-to-noise ratio. The seismic signals with heavy noise affect the result accuracy.

CONCLUSIONS

In this article, I introduced a new automatic first break picking method based on the STA/LTA fractal dimension algorithm. This method is based on the analysis of certain trace attributes. In this approach, short-time average, long-time average, and fractal dimension changes are calculated along the seismic traces within moving windows and analyzed to detect abrupt changes when the first break arrives. I performed my algorithm on a single trace (original and synthesized trace with adding white noise), and a shot gather acquired in a field seismic record in the west of Iran. The results showed that my proposed algorithm is quite reliable to determine the first breaks in seismic traces. This method is robust for seismic traces with low S/N and detects accurate picks even under the correlated noise, bad traces, and indistinct first breaks. Furthermore, this algorithm is computationally efficient and easy to apply. So, the operator needs to determine only the basic value of the STA/LTA ratio, and run the algorithm. This parameter is set based on the period and amplitude of the first arrival waveforms from a certain trace of a shot gather, which is easily determined by visual inspection, thus their selection is straightforward. In general, I have observed that considering the variations of STA/LTA with fractal dimension along the seismic traces together is very effective for picking first breaks.

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