Fractal Dimension of a Trace as a Tool for First Arrival Picking

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Abstract: Our eyes can recognize the arrival time of the signals by comparing the recorded amplitudes in various seismic traces. In this article we are trying to imitate this natural ability to find out a mathematical tool instead of eyes. Fractals are mathematical models, which are able to the job by analyzing the changes in the recorded amplitudes.

We present the results of applying an algorithm to pick automatically first arrival times in seismic records. The algorithm detects the presence of a signal by analyzing the variation in fractal dimension along the trace. Among the different evaluated methods, “divider method” was found to be the most suitable method for calculating the fractal dimension. A change in dimension was found to occur close to the transition from noise part of a trace to its signal plus noise part, which is in fact the first arrival. We found that the nature of this change varies from trace to trace, but a detectable amount of change is always occurring.

Keywords: fractal dimension, first break, automatic first arrival picking, divider method.

1 Introduction

The main problem in first arrival determination in recorded seismic traces is distinction between noise and signal. Sometimes accurate determination of first arrival of seismic waves is difficult even for experienced seismologists. Needless to say that, first arrival time determination is important in both applied and earthquake seismology. Some examples of their applications include: determination of seismic-velocity structure in refraction and VSP surveys, static corrections calculation in seismic reflection methods, and locating the epicenter of earthquakes. Recent interests for 3-D seismic data acquisition in oil industry require handling of huge amount of seismic data. As a result, computer aided picking of first arrival times is crucial. Researchers have already done various efforts in this regard. Gelchinsky, Krauklis and Moiseeva (1968), Neidell and Taner (1971), Peraldi and Clement (1972), and Gelchinsky and Shtivelman (1983) are some examples of these efforts. Most of them assumed that overall shape of the seismic pulse do not change considerably from trace to trace. However, such imagination about the head waves is not a true assumption. The method, which is introduced in this article is different from other previously applied methods, because it is not related to signal shape at all, rather it determines the first arrival times by considering the existing variations in the roughness of the noises and signals. In other words, the method is based on the contrast of fractal dimensions of noises and signals in the seismic trace.

2 Methods for fractal dimension calculation

There are various methods for calculating fractal dimension of curves, surfaces and volumes (Klinkenberg 1994). The most popular of them are divider, box counting, and power spectrum

methods (Turcotte 1992, Middleton 2000). In this study we utilized the divider method due to its better performance on curves as well as its simple required mathematics.

3 Divider method

Divider method can be used in number of ways. The most common way is divider stepping along the curve and recording the number of coverage steps (Fig 1). With regular increment in divider size and repeating the stepping process, the relation between steps sizes and curve length is determined. The relation is given by

$$L \approx N_i * r_i = r_i^{1-D} \quad (1)$$

Where L is the length of curve, N is the number of steps, r is the step size, and D indicates the fractal dimension of the curve.

Fig 1.a- A stage of stepping along the curve. In this stage curve is 8 times of the step size.

Fig 1.b- Another stage of stepping. This time curve is 3 times of the step size.

It is worthwhile to say that if the curve is a simple fractal, there will be only one slope in length versus step size plot, but if the curve is made of combination of two or more fractals with distinct dimensions, more than one slope will be seen in the plot.

Seismic traces are generally made of noises and signals combination (Fig 2). While they are inspected by divider method, trace length versus steps sizes plot will be looks like Fig 3 (Boschetti, Dentith and List, 1996).

Fig 2- A sample seismic trace.

Fig 3- A log-log plot of curve length versus step size.

To get plot in Fig. 3, minimum and maximum steps sizes were selected about sampling rate and $1/7$ (or $1/8$) curve length respectively. In Fig. 3, segment A of the plot belongs to those sizes of the step that are small enough to see all roughness on the trace. B and C are segments where the fractal behaviors of noise and signal are shown respectively. Segment D corresponds to those step sizes that are so big and are not any more able to see the roughness of the trace. The last segment E shows the effect of the stepping residuals. Residuals are in fact the last part of the traces, which are smaller than step size and generally are not accounted. The bigger the step sizes become, clearer are these effects. Therefore, running the algorithm with bigger step sizes takes less run time but reduces the algorithm's efficiency.

Since fractal dimension of signals within a seismic trace obtained from segment C of Fig. 3, an algorithm was written to recognize automatically this segment on the log-log plot of curve length versus step size.

4 Algorithm description

Our code performs calculations in two steps. At the first step, the range of fractal behavior of seismic trace is determined, then the other part of the code determines the fractal dimension. This is shown conceptually in Fig. 4.

Fig 4- Moving inspection window on the seismic trace.

A window with an arbitrary length is selected and slid on the seismic trace. At each position of the window the necessary calculations are made and corresponding log-log plot of curve length versus step size are plotted. From each plot, segment C is recognized and fractal dimension of the trace at the current position of window is calculated. Finally, plotting fractal dimension value with respect to window position indicates the sample of trace at which fractal dimension changes (which is the indicator of first arrival time).

In order to evaluate the performance of the algorithm, width of the inspection window was selected to be as long as 100 sample intervals. It moved 10 sample intervals toward the end of trace at each step and necessary calculations was performed. The calculated fractal dimension of each step was assigned to the position of sample 80 within the window. This delay is selected to provide enough time to algorithm to look for possible changes in the fractal behavior of trace. An example of the results is shown in Fig. 6.

Fig 5.a- A seismic trace used to test code performance.

Fig. 5 indicates a seismic trace used to evaluate the performance of algorithm. Direct estimation of first arrival time by simply looking at the enlarged version of the seismic trace suggests the location of sample 203 as first arrival time.

Fig 5.b- Enlarged version of the seismic trace as in Fig. 5a.

Fig 6 – Fractal dimensions in moving window

Divider method, on the other hand, recognizes the location of the first arrival with a sudden change in the fractal dimension of trace. In order to reduce the run time, a limited part of trace that contains first arrival was used. Also, to perform a robust inspection, window was moved toward the end of trace every sample at each step. Applying these considerations makes the algorithm accuracy to be one sample.

Fig7- Fractal dimensions when window move toward only one sample each time

Application of the method on seismic traces with different rate of S/N indicated that the amount of error depends on signal to noise ratio. Sometimes the error is reduced with better selection of window width and the place where the value of the fractal dimension is assigned.

5 Conclusion

This study recognized the divider method more suitable than other fractal dimension calculating methods. In selecting the parameters for algorithm, S/N ratio of seismic traces should be considered. As the contamination gets larger, the program parameters should be determined with more repetitions and assessments.

In fractal method, like other methods, first arrival determination should be performed regarding the immediate traces. Finally, we found fractal method is considerably slower than other methods but is more robust.

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