GeoConvention
Calgary • Canada • March 7-11 2016
OPTIMIZING RESOURCES

Picking of first-arrival times on very large seismic datasets

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Summary

Determining first-arrival times from high-volume 3D datasets with many millions of seismograms requires fast, automatic picking procedures. I present a processing flow that uses a modified energy ratio (MER) attributes to identify the first-break times of arrivals on common source gathers. Near the hyperbola apexes that bracket the first arrivals on the common-source gather, the signal-to-noise ratios (SNRs) are generally very high, so the MER picks are very close to first-break times. At the far flanks of the hyperbolas, the seismogram amplitudes are small, and a signal-enhancement technique employing three-trace summation along a range of time-space slopes must be to increase SNRs before MER picking.. At the far flanks of the CSGs, first-arrivals closely follow linear trends. The flow examines trace-to-trace differences in the MER picked times, and eliminates those picked times with deviations exceeding a mean deviation value or the observed average dominant period of the arrival wavelets. The remaining pick times and their receiver positions are fitted with a least-squares straight line. Interpolation is then used to fill in estimated first-break for those receivers with missing or deleted first-break times.

Introduction

First-arrival picking on seismic survey data is a ubiquitous and fundamental task in seismic processing. It provides the arrival times required by refraction analysis for determining the velocities and thicknesses of near-surface low-velocity zones. First-arrival times from full-waveform sonic well logs and VSP seismograms are needed to calculate interval velocities in a well. Arrival times are also required for locating focal points of global earthquakes and microseisms caused by hydraulic fracturing. Han et al. (2009) and Han (2010) have proposed a modified energy ratio (MER) as an alternative to the STA/LTA ratio (Coppens, 1985; Saari, 1991; Withers et al., 1998) to be used as a basis for first-break time-picking.

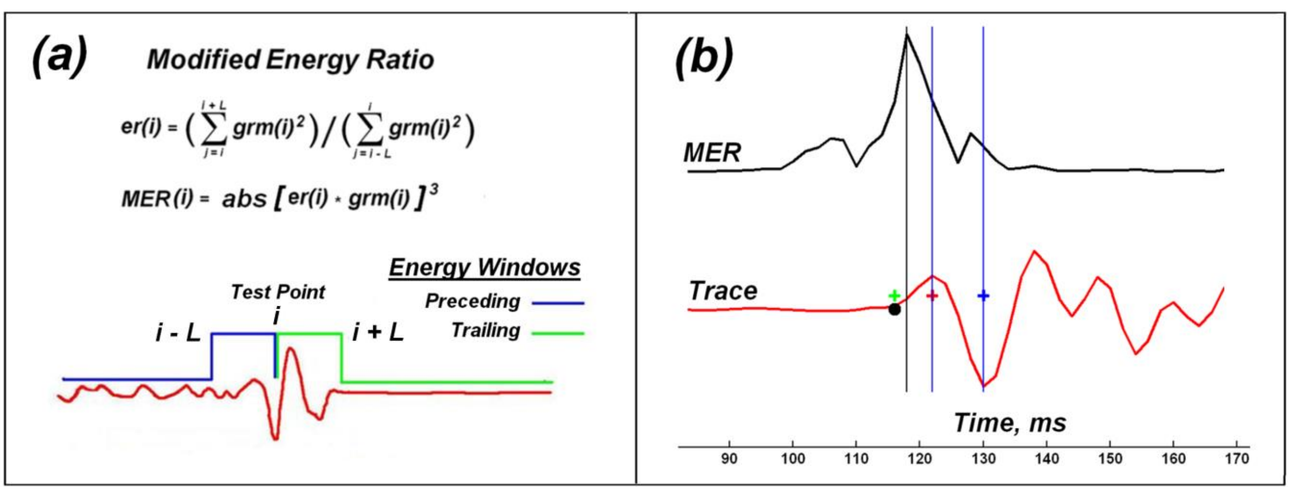

Fig. 1: (a) Energy and modified energy ratios at a test point with time index *i*. *L* is the length of the energy collection windows. (b) Vertical black line is the time t_{MER} of the peak MER value; the black dot indicates the estimated first-break time $t_{B1} = t_{MER} - \Delta t$. Red and blue crosses indicate the first peak and trough times t_{PK} and t_{TR} following time t_{B1}; The green cross is located at t_{B2}, a second estimate for the first-break time.

This paper describes a fast, automatic technique using an extension of the MER concept. The extension minimizes picking errors due to polarity changes and cycle-skipping.

Modified energy ratio (MER) attribute

Figure 1(a) summarizes the definition and use of the energy ratio and MER attribute for a digitized seismic trace sampled with time Δt. The energy ratio at a test point *i* on the digitized seismogram is

$$er(i) = (\sum_{j=i}^{i+L} grm(j)^2 / \ \sum_{j=i-L}^{i} grm(j)^2 \ , \quad (1)$$

where $grm(i)$ are trace amplitudes. In the summations, if the running index *j* is less than 1, set *j* to 1; if *j* exceeds *M* the length of the seismogram, set *j* to *M*. The MER attribute for the seismogram is

$$mer(i) = [abs(grm(i)) * er(i)\ ]^3\ . \quad (2)$$

Equation 2 is independent of signal polarity. Figure 1(b) is an example showing how the first-break time t_{B1} of a seismic trace (plotted in red) is estimated from the peak value of the MER attribute (plotted in black). The peak value of the MER attribute occurs somewhat later than the perceived first-break time. On common-source-gathers with noisy traces, the peak and trough times immediately following t_{B1} shows more trace-to-trace consistency. In such cases, an auxiliary estimate t_{B2} for the first-break time is useful:

$$t_{B2} = [(\ T_{MIN} - 0.25 * T_D) + (T_{MAX} - 0.75 * T_D)]/2\ , \quad (3)$$

$$T_D = 2 * abs(t_{PK} - t_{TR})\ \ , T_{MAX} = max(t_{PK}, t_{TR})\ , T_{MIN} = min(t_{PK}, t_{TR})\ ,$$

The times t_{PK} and t_{TR} are the trace peak and trough times from Figure 1(b); T_D is the dominant period of the arrival wavelet following the estimated first-break time t_{B1}. The difference between the MER pick t_{B1} and the auxiliary pick t_{B2} may be used as a figure of merit for quality control (if the difference is less than some small fraction of the dominant period, the picked first-break time for a particular seismograms is considered to be “good”).

When doing time-picking on field data, the signal-to-noise ratios (SNRs) of the first arrivals is an important consideration. For a given digitized seismogram, the SNR (expressed in decibels) of the first arrival is

$$SNR(i) = 10 \cdot \log_{10}[\ \sum_{j=i}^{i+L} grm(j)^2 / \ \sum_{j=i-L}^{i} grm(j)^2)\ ]\ , \quad (4)$$

where i is the time index of the first-break time pick. The term within the square brackets is the energy ratio in Equation 1.

First-arrival time picking on common-source gathers

Figure 2 displays an example of a common-source gather consisting of 138 field seismograms spaced at 50m intervals. Prior to time-picking, we applied a (20-40-80-160) Hz bandpass filter to reduce surface wave amplitudes and normalized each trace by its maximum amplitude. An initial pass of first-arrival picking based on the MER attribute was done, and the resulting initial first-break times are plotted on the figure as small red crosses. There are outlier picks at position with far source-receiver offsets. Figure 3 shows that, at the far offset positions 0m to 2500m, both the amplitudes and SNRs of first-arrivals are small. We kill any trace with maximum amplitude less than 80 db and SNR less than 10dB by setting the entire trace to zero. Then, after windowing the seismograms on the CSG using a retention corridor, we do a second iteration of MER picking to obtain improved estimates for the first break times. To determine a suitable retention corridor, we first do a least-squares fit of the initial MER time picks to the hyperbolic equation for normal moveout (NMO) trajectories

$$t_r = \sqrt{(t_0^2 + [(x_r - x_s)^2 + (y_r - y_s)^2]/v_0^2}\ , \quad (5)$$

where t_r is the NMO time of a receiver at position (x_r, y_r) separated from a source at position (x_s, y_s). We find optimal values of the parameters t_0 and v_0 that minimizes the least-squares differences between to the NMO times t_r and the initial MER times t_{B1}. Once a suitable NMO hyperbola is found, we shift it up so that it lies entirely above all the first arrivals on the CSG. We shift it down to create a second hyperbola that lies entirely below all the first arrivals on the CSG. The two hyperbolas define a retention corridor containing the first arrivals. We obtain reduced seismograms by muting all trace values outside the retention corridor, and resetting zero time to be at its ledge edge. We perform a second pass of MER first-break picking on the reduced seismograms. We keep track of the original times of the leading edge, so we can add them back to the second pass of MER picks.

The CSG of reduced seismograms and the second-pass MER estimates of first-break times for our example are plotted on Figure 4. The information on both Figures 3 and 4 clearly shows that a divide in the quality of the first arrivals occurs at receiver position 2500m.

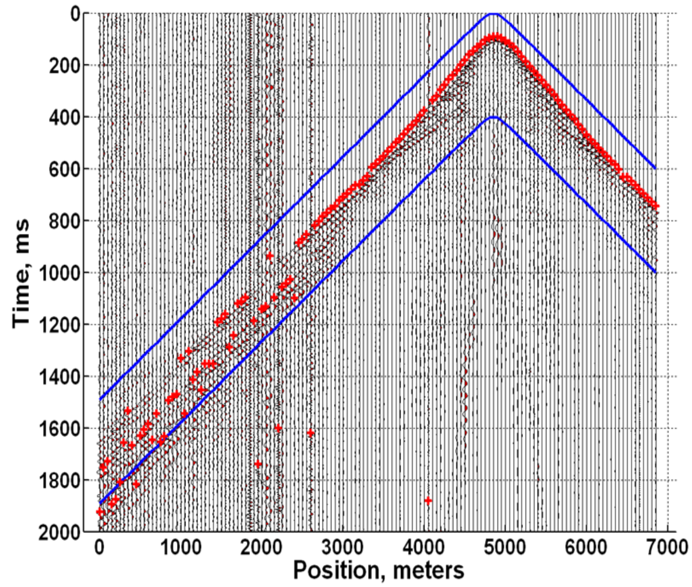

Fig. 2: Trace-normalized common source gather. Red crosses are first-break times t_{B1} from an initial application of MER first-break time-picking. Blue lines.are the limits of the retention corridor (width = 400ms, or about 10 to 15 dominant periods).

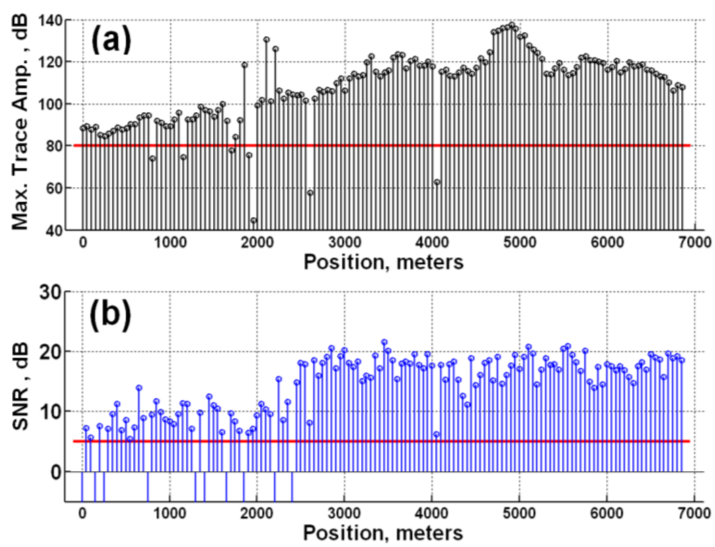

Fig. 3: (a) Maximum amplitudes used to normalize the traces on Figure 2. (b) SNR values at the MER times on Figure 2. The 5dB level is shown by the red line.

Picking on arrivals with low SNRs

For receiver positions less than 2500m at the far left flank of the CGS of reduced seismograms, many outliers and large gaps in the time picks can be seen on Figure 2. Figure 5 displays the reduced seismograms for positions from 0m to than 2500m, where we see more clearly the outliers and gaps in the second-pass time picks. The gaps are due to killed traces and rejection of picked times with SNR values less than 10dB. For each trace k on this figure, we calculate the time deviation,

$$t_{Dev1}(k) = abs\big(t_{B1}(k+1) - t_{B1}(k)\big) .$$

We reject any time for which the deviation exceeds a threshold value related to the mean of the deviation. A least-squares fitting straight line is found based on the remaining $t_{B1}(k)$ values. New deviations t_{Dev2} of the base values t_{B1} from the straight line are found, and any base value with a deviation exceeding $T_D/2$ is rejected. The remaining base values are used to find a new best-fitting straight line.

Rejecting outlier base points to find updated best-fitting straight lines is repeated until the mean value of t_{Dev2} is less than ~$T_D/4$. Then, any gaps in the time picks due to rejection of outliers or killed traces can be filled with straight-line interpolated values. For each receiver position, median filtering of the interpolated value with two auxiliary estimates based on the following peak and trough times (the two terms on the right-hand side of Equation 3) may yield an improved estimate of the first-break time.

Figure 5 is a plot of far-offset seismograms for our example after signal enhancement using a three-trace summation for each digital point on each seismogram. The summation is done along a range of slopes, and the trace value at the digital point is replaced by the maximum sum. There are two events showing good coherence with apparently linear moveout. The enhanced CSG is split at 150ms, and each half is trace-normalized. MER picks are made on each half, and the procedure for fitting a linear trend for non-outlier MER picks is applied. The resulting best estimates for the first-break times for the two linear events are plotted as blue dots. Rejected outlier MER picks are plotted as black dots.

Conclusion

I have described an automatic scheme for picking first-arrival times on common source gathers based on the modified energy ratio (MER), an attribute that is simple and fast to calculate, making it attractive to use in an automated flow for first-arrival time picking on large datasets. The **scheme** has been tested a common-source gather with 138 traces, but it can be applied repeatedly for as many CSGs as are available in very high-volume 3D seismic datasets.

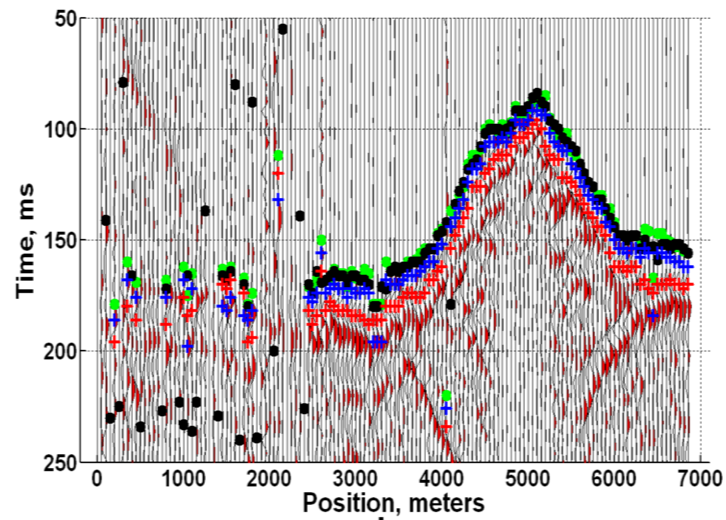

Fig. 4: Reduced traces within the retention corridor of Figure 2, Black dots are the second pass MER first-break picks t_{B1} Red and blue crosses are the peaks and troughs immediately following t_{B1}; green crosses are the auxiliary estimates t_{B2} of the first-break times.

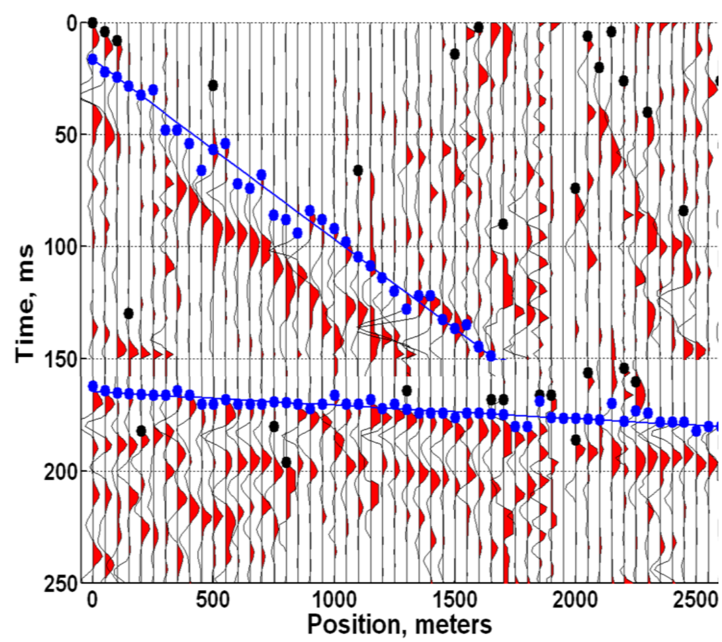

Fig. 5: Reduced traces at the far left flank of the CSG, enhanced by three-trace summation. Blue dots are time-pick estimates interpolated from the linear trend (derived from non-outlier MER picks). Black dots are outlier MER picks.

Acknowledgements

CREWES is supported financially by its industrial sponsors, and also is funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) under Grant CRDPJ-461179-13.

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