Weighted Correlation Pairs for Improved Velocity Analysis

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SUMMARY

Automatic stacking velocity analysis of seismic reflections often involves calculating a coherency measure (such as semblance) along a range of hyperbolic trajectories at a time T_0. Most coherency measures are formulated so that the maximum coherency value can be assumed to be the correct stacking velocity for the time T_0. It is therefore very important that the formulation of the coherency measure uses the maximum amount of the velocity information in the data in order to minimize the uncertainty in the velocity determination. The purpose of this paper is to introduce a coherency measure that is a modification of semblance that provides more accurate velocity estimation than standard semblance. The coherency measure is a normalized sum of weighted correlations between trace pairs in a CDP gather. The weighting applied to the trace-pair correlations is proportional to the reflection travel time difference between the two data traces. This weighting is used because trace pairs that have a large difference in travel time for a given reflection contain more velocity information than trace pairs that have nearly the same reflection travel time.

INTRODUCTION

Automatic stacking velocity analysis for CDP seismic data is commonly done by generating a plot of the coherency measured across a CDP gather over a range of time-velocity pairs. The velocity for a given time is generally picked to be the one with the highest coherency, as long as it is a reasonable velocity and it is consistent with the other time-velocity pair picks in the velocity spectrum. By far, the most common coherency measure in use today for seismic data is the semblance measure (Neidell and Taner, 1971). Semblance probably is so widely used because it has proven to be robust and it is relatively inexpensive to calculate. Note that most papers that discuss new coherency measures use semblance as the standard of comparison, Key and Smithson (1990) for example.

The purpose of this paper is to introduce a modification of the semblance coherency measure that improves stacking velocity resolution over that provided by standard semblance. The coherency measure is based on the following ideas. Assume that the reflection from an interface is recorded at two different offsets, X_1 and X_2. The travel time for the reflection at offset x is T(x). The travel time difference, dT, is expressed as

$$dT = T(X_2) - T(X_1)\,.$$

If dT is large then the NMO correction process will align the reflection on the traces at X_1 and X_2 ONLY when the stacking velocity is near to being correct. When the reflections are aligned then there is high coherency between the two traces at the time of the reflection. If however, X_2 is nearly the same as X1, then dT will be small. The reflection will then be nearly aligned (have a high coherency) for a wider range of velocities than when dT was large. There is therefore greater uncertainty in the correct stacking velocity provided by trace pairs with small values of dT than for trace pairs with large values of dT.

Our proposed coherency measure is the normalized sum of weighted correlations between trace pairs in a CDP gather. The weighting coefficient that is applied to each trace pair correlation depends upon the weighting scheme used, but in general is proportional to dT. The weighting scheme used should allow for reflection character changes as a function of offset and differences in signal-to-noise ratio at near and far offsets.

THE SEMBLANCE MEASURE

Neidell and Taner (1971) define semblance, Sc, as in Equation (1) below.

$$S_c = \sum_{i=1}^{M} \sum_{j=1}^{M} \frac{R_{ij}(0)}{MP} \qquad (1)$$

where Rij is the unnormalized correlation coefficient between traces i and j in a time window. P is the power in the analysis window and M is the number of traces in the winodw. The semblance measure has the nice property that its maximum value is 1.0 for a perfect correlation across the gather and a minimum value 0.0 for no correlation across the gather. As mentioned above, the semblance measure normally does a good job of estimating the correct stacking velocity in a wide variety of signal and noise conditions.

PROPOSED MODIFIED SEMBLANCE MEASURE

The premise of this paper is that more reliable velocity information can be extracted from CDP data if the correlations between trace pairs are weighted by a factor that is in some way proportional to our previously-defined dT. Thus we rewrite Equation (1) above as Equation (2)

$$C = \sum_{i=1}^{M} \sum_{j=1}^{M} \frac{R_{ij}(0)W_{ij}}{MP} \qquad (2)$$

where C is our proposed coherency measure and Wij is the weighting coefficient for the pair of traces i and j. Note that Equation (1) is just a special case of Equation (2) in which Wij = 1.0 for all i,j.

WEIGHTING SCHEMES

We seek a weighting scheme such that the trace pairs that provide the most velocity information are most heavily weighted in their contribution to the coherency measure C. In general then, the weighting function Wij increases as the travel time difference between correlation pairs increases. The hyperbolic moveout equation is shown below in Equation (3).

$$T^2_x = T^2_0 + \frac{x^2}{V^2} \qquad (3)$$

where T_x is the approximate two-way travel time of a reflection at offset x and stacking velocity V and zero-offset two-way time of T_0. A straightforward weighting scheme is to weight correlation pairs based on the travel time difference between trace pairs given by Equation (4).

$$W_{ij} = T(X_i) - T(X_j) \qquad (4)$$

Note that if $i = j$, then $W_{ij} = 0$. This is appropriate since a data trace correlated with itself provides no velocity information. In the semblance measure, a trace correlated with itself is given the same weight as the correlation between a near-offset trace and a far-offset trace. We are currently analyzing the coherency estimate in Equation (4) and finding that improvments can be gained by using the weighting function

$$W_{ij} = \frac{(X_i^2 - X_j^2)^2}{1 + k_2 X_i^2 X_j^2} \qquad (5)$$

where k_2 is proportional to the variability of the data in the analysis window. This formulation is derived from beam forming theory. Equation (5) suppresses the effects of variations in signal-to-noise ratio with offset, NMO stretch, and variable frequency content with increasing offset. A large number of weighting schemes are possible, we presented the one above as an example to illustrate the ideas presented here.

APPLICATION TO REAL AND SYNTHETIC DATA

We applied the weighting scheme in Equation (4) to both real and synthetic seismic data and compared the results to semblance. Figure 1 shows a real CDP gather with a strong event at 850 ms (pointed to by the arrow). Figure 2 shows a plot of coherency across the CDP gather at 850 ms for a range of velocities. The coherency curves shown are for semblance and our weighting method in Equation (4). Both curves are normalized to the maximum coherency value of the respective curves for easy comparison. Note that the velocity function is more sharply defined for the weighted coherency measure. We also tested our coherency measure on synthetic data so that we would know the correct stacking velocity of the events. The modified semblance measure provided more sharply-defined and more accurate velocity information than semblance for all of the cases, which included signal-to-noise ratios ranging from 0.5 to 10.0.

COMPUTATION TIME

Computation time for our proposed methods are greater than for semblance because the numerator of the semblance measure can be calculated as the square of the sum of values across a CDP gather at a given time. For M traces in a CDP gather, the number of operations required for semblance calculations is on the order of M. In our method, the number of operations required is on the order of M squared. We have found however, that several short cuts can be taken that reduce the computation time of our coherency measure so that it takes only 20% to 30% longer than the semblance calculation.

CONCLUSIONS

Velocity can be more accurately estimated from a CDP gather by using the coherency measure presented in Equation (2) rather than the standard semblance measure. In general, the value of W_{ij} in Equation (2) increases with increasing difference in event travel time on the pairs of traces in the correlation. Weighting schemes will be somewhat data dependent because of variations in data as a function of offset.

References:

Key, S. and Smithson, S. B., 1990, New approach to seismic-reflection event detection and velocity determination: Geophysics, 55, 1057-1069.

Neidell, N. S., and Taner, M. T., 1971, Semblance and other coherency measures for multichannel data: Geophysics, 36, 482-497.

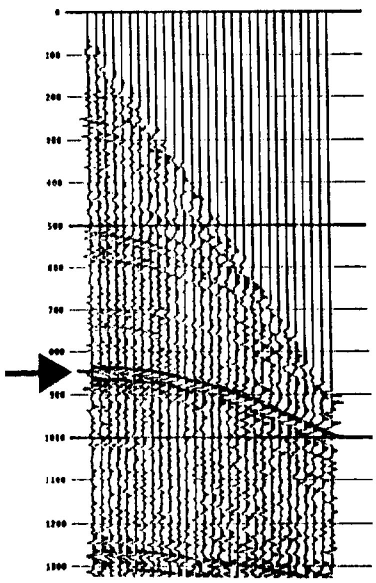

Figure 1. CDP gather. Arrow points to event at 850 ms.

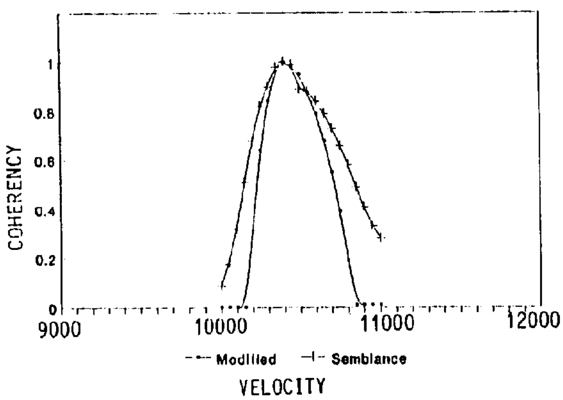

Figure 2. Velocity (ft/sec) VS Coherency. Curve with dots is for modified semblance, curve with plus signs is for semblance.