Advances in coherence computation - multispectral and multiazimuth

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The iconic coherence attribute has been widely used for mapping of geologic features such as faults, channels, karst collapse, stratigraphic edges, and more. The quality of the generated coherence attribute is dependent on the quality of the seismic data, yielding cleaner and clearer images for data that have been imaged well, and have higher signal-to-noise ratio. The quality of the generated coherence is also dependent in part on the algorithm employed for its computation. The coherence attribute was first introduced two and a half decades ago with the application of the cross-correlation algorithm (Bahorich and Farmer, 1995). Thereafter, semblance (Marfurt et al., 1998), variance, prediction error filtering (Bednar,1998), eigenstructure decomposition of covariance matrices (Gersztenkorn and Marfurt, 1999), geometric structure tensor (Bakker, 2002) and energy ratio algorithms (Chopra and Marfurt, 2007) were developed. These algorithms vary in how they handle seismic character variability, and thus have different sensitivities to geology, spectral bandwidth and seismic noise. Out of these, the most commonly available algorithms in workstation software packages are semblance and some form of eigenstructure decomposition.

As most of the covariance matrices we come across in attribute analysis are square, they are decomposed into non-negative eigenvalues, and so can be written in the forms as shown below.

$$\mathbf{Cv}^j = \lambda_j \mathbf{v}^{kj} , \qquad (1)$$

where **C** is an *M* by *M* square covariance matrix, λ_j is the j^{th} eigenvalue, and $\mathbf{v}^j$ is the corresponding eigenvector.

The eigenstructure coherence described by Gersztenkorn and Marfurt (1999) was simply given as the ratio of the first (and by definition, the largest) eigenvalue to the sum of all the eigenvalues of the matrix:

$$C_{eigen} = \frac{\lambda_{max}}{\sum_{j=1}^{J} \lambda_j} . \qquad (2)$$

Marfurt (2006) described the principal component structure-oriented filtering, where the principal component filter first constructs a covariance matrix from the 2K+1 sample vectors, and then computes eigenvectors prior to cross-correlating it with the center sample vector. Such a procedure provides a means of computing a principal component filtered version of the data, in terms of $\mathbf{d}_{PC}$ and $\mathbf{d}_{PC}^{H}$.

The energy ratio coherence is thus a slightly more general computation given as:

$$C_{Energy\ ratio} = \frac{\sum_{k=-K}^{+K} \sum_{m=1}^{M} \{[d_{PC}(t_k, x_m, y_m)]^2 + [d_{PC}^{H}(t_k, x_m, y_m)]^2\}}{\sum_{k=-K}^{+K} \sum_{m=1}^{M} \{[d(t_k, x_m, y_m)]^2 + [d^{H}(t_k, x_m, y_m)]^2\}} \,. \qquad (3)$$

In the above mathematical expression, the numerator can be interpreted as the energy of the weighted principal component filtered analytic traces, and the denominator as the sum of the energy of the analytic traces or total energy. In simple notation, the energy ratio coherence may be given as:

$$C_{Energy\ ratio} = \frac{E_{coh}}{E_{tot}} \,. \qquad (4)$$

Regarding the comparative performance of semblance and eigenstructure algorithms on real data, invariably, as was demonstrated by Gersztenkorn and Marfurt (1999), the eigenstructure algorithms depict superior images than the semblance algorithm. One can easily notice the sharp, crisp and more continuous definition of the lineaments seen on the energy-ratio displays, though price must be paid for the higher computation time.

Consequently, all the examples of coherence shown in this work are generated using the energy-ratio algorithm.

In the last couple of years, the additional information provided by running coherence on different spectral components of seismic data have been demonstrated. For convenience in interpretation, instead of running coherence on selected spectral components, and/or combining them using RGB type of color schemes, coherence on spectral components has been combined into a single volume. This is done by modifying the covariance matrix to be the sum of the covariance matrices, each coming from an azimuthally-limited volume, and then using the summed covariance matrix to compute the coherent energy (Marfurt, 2017). Such a computation has been referred to as *multispectral* coherence.

Finally, with the focus on shale resource plays, wide azimuth surveys are being commonly being acquired. Such surveys provide better quality data in terms of less coherent noise coming from ground roll, and interbed multiples, as well as azimuthal anisotropy analysis. Coherence on azimuth-sectored data has been demonstrated before, and though it exhibits better lateral resolution, it is found to be noisy. Similar to multispectral coherence, the covariance matrix is modified to be the sum of the covariance matrices, each coming from an azimuthally limited volume, and then using the summer covariance matrix to compute the coherent energy (Qi et al, 2017). This computation is referred to as *multiazimuth* coherence.

We demonstrate the applications of multispectral and multiazimuth coherence on real seismic data, and show the added value they provide for interpretation of geologic features that is always being sought.

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