SPECTRAL DECOMPOSITION AS A QUALITY CONTROL TOOL IN 5D INTERPOLATION

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Summary

Spectral decomposition as its name suggests, separates or decomposes the seismic wave into its different spectral or frequency components. The application of this technology to seismic data in the last two decades, has been primarily to qualitatively and quantitatively interpret stratigraphic and structural traps. Very little has been done to use spectral decomposition as a quality control (qc) tool in routine seismic data processing.

In this work and with the aid of a 3D seismic data from South Texas, it is demonstrated that spectral decomposition can reveal geological structure better for processing qc than just using conventional amplitude time slice. Also, it is shown that spectral decomposition has the capability to reveal subtle processing artifacts which may otherwise be missed in 5D interpolation processing.

Introduction

Spectral decomposition in the last two decades has evolved to be a very useful tool in seismic interpretation to map stratigraphic and structural features as well as estimating the reservoir thickness at tuning frequency. The concept of spectral decomposition is based on the theory that different geological features in any broadband seismic data will show up or tune in at different frequencies. By decomposing the data into its different frequency components therefore, we stand a better chance of imaging interesting geology that may otherwise be hidden in the broadband data. This same concept holds true for noise and other processing artifacts in the data. By looking through different frequency slices, some noise and artifacts may tune in better than looking at the broadband data as a whole.

Since the advent of Fourier transform, conventional seismic data processing for ages has always used the concept of spectral decomposition to analyze data, even though it was not so expressly called. For instance, in removing high amplitude and low frequency noise such as ground roll, the low frequency part of the data is separated and analyzed for noise suppression. A second example is in eliminating power line noise which is always inadvertently recorded with the data in seismic acquisition. The noisy frequency of 50Hz or 60Hz depending on the location, is separated, analyzed and suppressed instead of applying a notch filter that will take away both signal and noise frequency. A third example is in AVO-compliant processing where high amplitude noise bursts are separated based on their frequencies, analyzed and suppressed. A fourth example of the application of spectral decomposition in seismic data processing is in running narrow band filter tests where strips of frequencies are separated from the data and analyzed to determine the final filter of the processed data before delivery to the interpreter.

For delineation of stratigraphic and structural features in seismic interpretation, Partyka et al. (1999) first introduced the concept of spectral decomposition in the literature. Since then, a number of authors have come up with different ideas and methods of estimating the attribute in seismic data analysis.

In seismic interpretation, four major methods are used in spectral decomposition:

- Short time Fourier transform (STFT) or short window Fourier transform (SWFT), Partyka et al. (1999).
- S transform (ST), Stockwell et al. (1996).
- Continuous wavelet transform (CWT), Burnett et al. (2003).
- Matching pursuit (MP), Castagna et al. (2003).

The other methods in the literature are for the most part variations of the above mentioned four techniques. Any of these methods can be used depending on the objective of the spectral decomposition analysis.

Method

De Abreu et al. (2017) described a case study, where spectral decomposition using the continuous wavelet transform (CWT) method and frequency-dependent coherency attributes, were used to qc and judge between two 3D seismic datasets acquired at different times for their geological interpretability.

In this study, a different approach was employed to analyze the data using spectral decomposition. The short time Fourier transform (STFT) method was used to qc a 3D land seismic data from South Texas processed to prestack time migration with and without 5D interpolation. For the purpose of this work, the dataset processed to prestack time migration without 5D interpolation is called PSTM and the dataset processed to prestack time migration with 5D interpolation is called PSTM5D.

The simple four-step spectral decomposition workflow in this study involves:

- Volumetric spectral decomposition of each input dataset named PSTM and PSTM5D with a window of -20 to +20ms.
- Pick three frequencies based on the peak amplitudes as seen on the amplitude spectrum along the horizons of interest.
- Color stack or “RGBA blend” the three chosen frequencies and the similarity attribute.
- Display the horizon slices of the combined multi-attribute and compare the results for the two input datasets.

R which stands for red displays the highest frequency, G which stands for green displays the middle frequency, B which stands for blue displays the lowest frequency and A which stands for alpha displays the similarity or coherency attribute. This combined multi-attribute display helps in simultaneous analysis and presents stratigraphic and structural features along the horizons of interest with greater clarity and detail compared to single-attribute displays.

Example

The 3D land Vibroseis data used for this study was acquired in South Texas in USA. The total size of the survey is about 8.75 square miles with a total of 1038 shots and 1680 receivers. There are 15 east-west receiver lines spaced 1320 feet apart and 16 north-south shot lines spaced 880 feet apart. Distance between receivers is 110 feet and distance between shots is 220 feet. Sweep frequency is 8-120 Hz and sweep length is 14 seconds with a record length of 6 seconds and a sample rate of 2ms.

The data was sparsely shot and so was a good candidate for 5D interpolation testing. Since the receiver distance is 110 feet and shot distance 220 feet, the natural bin size is rectangular with a dimension of 55 by 110 foot. The inlines are east-west parallel to the receiver lines and the crosslines are north-south parallel to the shot lines. Figure 1 shows the basemap of the 3D survey.

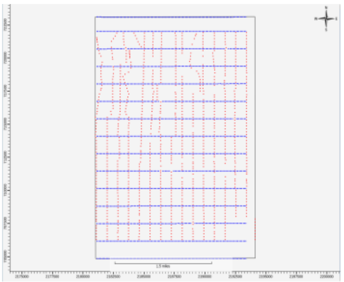

Figure 1: Basemap of the 3D survey. Receivers are blue and shots are red. Inlines are east-west. Crosslines are north-south.

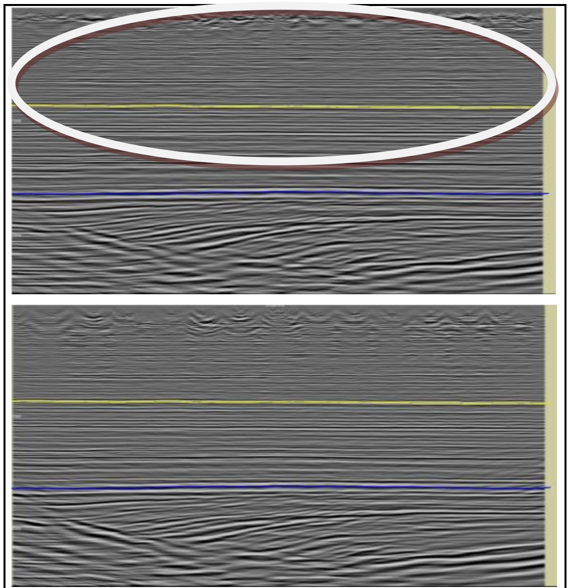

Figure 2: Top: PSTM5D. Bottom: PSTM. The obvious improvement of PSTM5D is the continuity in the shallow to mid-section as indicated by the white circle. Yellow and blue are the horizons picked for qc purposes.

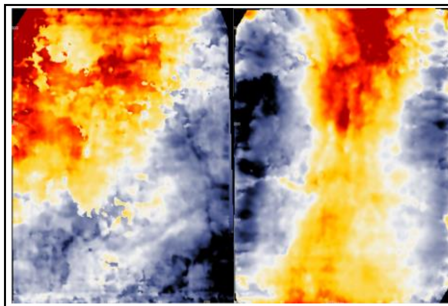

Figure 3: Time structure maps. Left: Yellow horizon. Right: Blue horizon. The yellow horizon shows a more stratigraphic structure while the blue horizon shows a north-south faulted anticlinal structure. High: Pink/red color. Low: grey/white color.

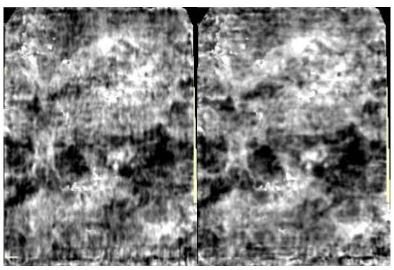

Figure 4: Amplitude slice of yellow horizon. Left: PSTM. Right: PSTM5D. The PSTM5D shows a clearer picture less affected by acquisition footprints.

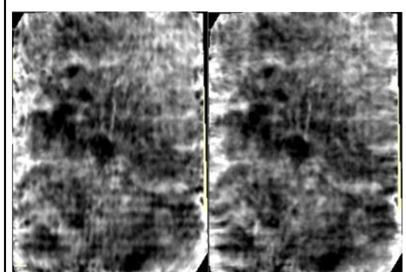

Figure 5: Amplitude slice of blue horizon. Left: PSTM. Right: PSTM5D. The PSTM5D shows a clearer picture.

As already mentioned, the data went through two different seismic data processing flows to prep the data for spectral decomposition and both processing flows were AVO-compliant. The first flow called the PSTM flow did not include 5D interpolation. Data was processed as a 55 by 110 foot bin survey and then prestack migrated out to 55 by 55 foot bin. The second flow, the PSTM5D flow included 5D interpolation. Data was processed as a 55 by 55 foot bin survey, upsampled using a prior 2D interpolation to minimize the effect of aliasing, 5D interpolated and then prestack time migrated. Kola-Ojo (2017) has described with tests, the benefit of running a prior 2D interpolation before 5D interpolation. The reason for upsampling to a smaller bin size is to reduce smearing of the data, thereby sharply preserving the faults and other subtle structures. The same statics and velocities were applied in both processing flows and did fit the datasets very well, with the added advantage of not introducing inconsistent errors that may bias the spectral decomposition results.

Figure 2 shows an inline section from PSTM and PSTM5D workflows/datasets. The yellow and blue horizons were picked for qc and data comparison. PSTM5D obviously shows better continuity than PSTM most especially in the shallow.

The time structure maps of the yellow and blue horizons are shown in Figure 3 as control structural maps for qc and comparison of the datasets. The structure maps tell us the general structural direction and features of each horizon and so can help us to quickly identify processing deficiencies and artifacts as we look through the horizon amplitude and spectral decomposition slices. As can be seen in Figure 3, the yellow horizon shows a more stratigraphic and channel-like feature while the blue horizon shows a broad north-south faulted anticlinal structure. In the Figure, red/yellow is high and grey/white is low. Figure 4 shows the amplitude slice of the yellow horizon for PSTM and PSTM5D. PSTM5D is better as it

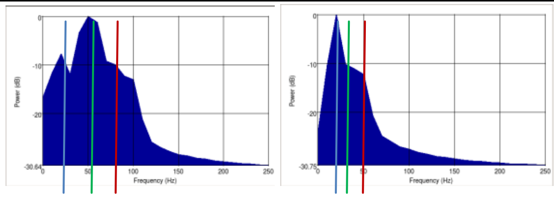

Figure 6: Amplitude spectra of the horizons. Left: yellow horizon. Right: blue horizon. The highlighted frequencies for each horizon were used for RGBA blending.

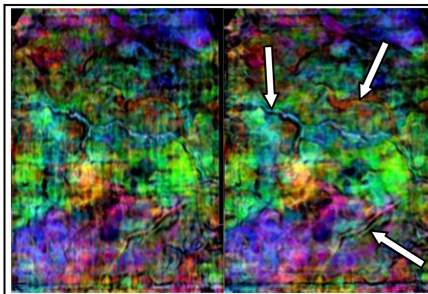

Figure 7: Spectral decomposition of yellow horizon. Left: PSTM. Right: PSTM5D. The meandering channel structure is much clearer on the right as indicated by the white arrows.

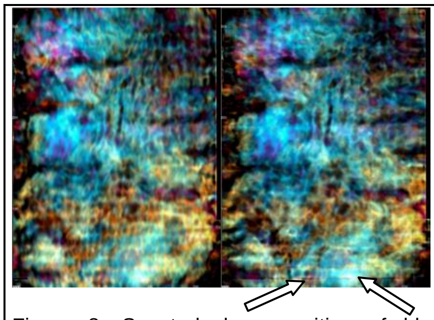

Figure 8: Spectral decomposition of blue horizon. Left: PSTM. Right: PSTM5D. We see some east-west artifacts or events in PSTM5D as indicated by the white arrows. These events are not present in the time structure map of Figure 3 and so are not real events.

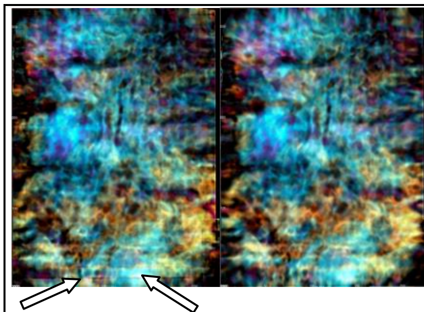

Figure 9: Spectral decomposition of blue horizon. Left: PSTM5D with artifacts as shown by the white arrows. Right: PSTM5D with artifacts removed.

is less affected by acquisition footprints. Figure 5 shows the amplitude slice along the blue horizon. We also see an improvement of PSTM5D over PSTM. To know the three frequencies that would be “RGBA blended” after spectral decomposition, the amplitude spectra over the horizons were examined. The frequencies chosen for the yellow horizon were: 20, 55 and 80Hz while the frequencies chosen for the blue horizon were: 20, 35 and 50Hz. Figure 6 shows the amplitude spectra of the horizons with the chosen frequencies highlighted with red, green and blue. Red is for the highest frequency, green for the middle frequency and blue for the lowest frequency. Figure 7 shows the spectral decomposition results (after RGBA blending) of the yellow horizon. The meandering channel structure is much clearer and better imaged in the PSTM5D dataset. Compared to Figure 4 where the horizon amplitude slice was unclear, we can now see the results better and qc the 5D interpolation by looking at actual geological structure. Figure 8 shows the spectral decomposition results of the blue horizon. We see some artifacts in the PSTM5D that were difficult to see in Figure 5 showing the horizon amplitude slice. These artifacts are as a result of insufficient offsets allowed in the 5D stack after prestack time migration. By allowing sufficient offsets into the 5D stack, we completely remove these artifacts as shown in Figure 9. Spectral decomposition has helped us to see the artifacts generated by the 5D interpolation processing.

Conclusions

The spectral decomposition results has helped to qc the processing of this 3D dataset from South Texas.

Acknowledgements

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