Comparative Study of Spectral Decomposition Methods and Their Implication in delineation of Geological Features: A Case Study From North Assam Shelf, India

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Summary
In seismic exploration, spectral decomposition refers the method of decomposing the input seismic trace into time-frequency domain. Frequency spectrum is output for each time sample of the seismic trace, which can be applied through various decomposition techniques to have geological features identification and comparison. This methodology provides continuous analysis of amplitude, frequency, phase, and energy spectrum. Therefore, Spectral decomposition is used to obtain an amplitude spectrum of frequency content of seismic trace, which is attributed to the temporal center of the sample trace; so higher time resolution is achieved at higher frequencies.

There are different methods of spectral decomposition like fast Fourier Transform (FFT), Continuous Wavelet transform (CWT), and Matching Pursuit Decomposition (MPD). These methods have their own advantages and disadvantages. So, it is very important to wisely use these methods for delineation of sub-surface geological features. FFT gives poor vertical resolution but better frequency localization. CWT gives better vertical resolution, but best vertical resolution is obtained using the MPD.

In this study, it has been demonstrated that how spectral decomposition methods such as FFT, CWT and MPD can be useful for delineating sub-surface geological features and results obtained from these methods are compared to showcase the significance of these methods in obtaining the strati-structural features.

Geology of area and challenges
The Assam & Assam Arakan Basin, India is bounded by the eastern Himalayan fold belt in the north, the Mishmi hills in the northeast and the Patkai – Arakan fold belt in the east (Figure-1). It is a typical poly-history basin having more than one phase of tectonics and sedimentation. In the Assam Basin extensional tectonics prevailed till Mid-Miocene when the tectonic regime changed to compressional during the major phase of Himalayan orogeny.

After Himalayan orogeny during Early Miocene time basinal slope reversal took place after deposition of Namsang sediments. This resulted in reactivation along faults, resulting in reverse faults and inverted structures along with re-adjustment of blocks as well as redistribution of hydrocarbons. The oldest fault trend in the area is NE-SW transected by the younger E-W to NW-SE trend creating a number of fault blocks.

Figure-1: Base map of the study area
The area of study (Figure-1) pertains to the Lakhmani high, which consists of a parallel network of normal faults oriented NE-SW at Tipam Top level. Hydrocarbon accumulation has occurred within Girujan sands through some of these faults during re-activation. It is also observed that Girujan sands are prospective over the areas where older underlying Tipam sequences are hydrocarbon bearing. Major challenge in this area is to map the thin discrete sands of 3m to 4m. Therefore, an effort has been made to image the geological features through application of various spectral decomposition methods.

Basic Theory
Spectral decomposition, decomposes the seismic signal into its constituent frequencies, and gives information about phase and amplitude tuned to specific wavelengths. The amplitude component gives information about thickness variability and detecting vertical discontinuities while the phase component detects lateral discontinuities.

More precisely, it is a tool for visualizing “below resolution” seismic interpretation, sand thickness estimation, and enhancing channel structures/geological features.

Here we are describing the role of different spectral decomposition techniques viz. FFT, CWT & Matching Pursuit in bringing out the channel geometry and illuminate geological features. The main challenge in this area is to map the thin sands, which is difficult through
conventional seismic interpretation methods. Thus, three advance techniques of spectral decomposition were used in the study and results were compared to visualize the effect in each of the method.

In general, FT gives the spectral content of the signal, but it gives no information regarding where in time those spectral components appear. For non-stationary signals algorithms like in STFT (Short-Time Fourier Transformation) the signal is divided into small enough segments, where these segments (portions) of the signal can be assumed to be stationary. But here also frequency components are well separated from each other in the original signal, and therefore we have to sacrifice some frequency resolution and go for good time resolution, since the spectral components are already well separated from each other. Frequency and time resolution cannot be obtained at one time. Wavelet transform solves this dilemma to certain extent. So, continuous wavelet transform still has a great disadvantage, however, the wavelets utilized must be orthogonal. The commonly used Morlet wavelet, it has poor vertical resolution due to multiple side lobes.

Matching pursuit decomposition (Mallat and Zhang, 1993) involves cross-correlation of a wavelet dictionary against the seismic trace. The projection of the best correlating wavelet on the seismic trace is then subtracted from that trace. The wavelet dictionary is then cross-correlated against the residual, and again the best correlating wavelet projection is subtracted. The process is repeated iteratively until the energy left in the residual falls below some acceptable threshold. As long as the wavelet dictionary meets simple admissibility conditions, the process will converge. Most importantly, the wavelets need not be orthogonal. The output of the process is a list of wavelets with their respective arrival times and amplitudes for each seismic trace.

The inverse transform is accomplished simply by summing the wavelet list and the residual, thus reconstructing the original trace. The wavelet list is readily converted to a time-frequency analysis by superposition of the wavelet frequency spectra. Matching pursuits gives better vertical resolution compared to CWT and FFT methods. The objective of matching pursuits is to obtain better vertical resolution in comparison to the standard methods of frequency decomposition. The resolution of this method is very close to that of the original input seismic, allowing to interpret on colour blends in vertical sections with more confidence.

The input data is used for the study is PSTM stack 3D volume. Before going to frequency decomposition application it is very important to condition input data for improvement in s/n ratio and apply spectral enhancement to enhance the geological continuity. Figure-2 shows minimal/no overlap, which will result in strong contrast between red, green and blue as observed in FFT. So, in case of FFT RGB blending shows good contrast of red, green and blue colors but poor vertical resolution. Figure-3 shows the amplitude verses frequency plot, used to differentiate between different geological elements, based on their bulk properties. Equal power in each RGB band, the scale is kept constant and the frequency modulation varied, so the bandwidth of the filters is constant and independent of the central frequencies.

Figure-2: Amplitude verses Frequency plot for FFT
(courtesy: Help manual of GEOTERIC)

Figure-3: Amplitude verses Frequency plot for FFT
(courtesy: Help manual of GEOTERIC)

A distinct separation between the various frequencies is observed here but due to the increasing RGB bandwidths there is an overlap. So RGB blend in case of CWT gives more ‘transitional’ colors in the blend by highlighting subtle variations and color (frequency) combinations and better vertical resolution compared to FFT.

Figure-4: Amplitude verses Frequency plot for FFT
(courtesy: Help manual of GEOTERIC)

Figure: 4 shows the data is split into 3 frequency bands, a low frequency, mid frequency and high frequency, prior to running Matching Pursuit algorithm. The underlying low frequency signal is matched to a dictionary of wavelets independently to the higher frequency events. In MFD, improved vertical resolution is obtained compared to FFT and CWT.
Results & Discussion:

Figure-5 and 6 shows the comparison of input PSTM stack data and conditioned PSTM stack data used for the study.

Figure-5: Input Seismic section

Figure-6: Spectrally Enhanced section

Seismic section clearly depicts the continuity within the Girujan zone. Figure-7 and 8 show the spectrum before and after application of noise cancellation and spectral enhancement which clearly demonstrate the improved resolution of input data.

This improved PSTM stack is used as the input for spectral decomposition methods i.e FFT, CWT & matching Pursuits for revealing the geological features.

Figure-7: Spectrum of input data

Figure-8: Spectrum of enhanced section

Figure 9 & 10 show the RMS & sweetness attributes extracted 20ms below Girujan Top, the probable channel features are clearly seen as high amplitude zones (yellow to red color) towards the north west side of the area.

Fig-11, 12 and 13 show the mono-frequency plots at 12, 20 & 30Hz below 20ms of Girujan Top extracted using matching pursuit spectral decomposition method. It is observed from the study that high amplitude anomaly observed at 20ms below the Girujan Top in RMS and sweetness attribute and presence of amplitude anomaly in all the three frequencies give indication of channel features.

Figure-9: RMS extracted 20ms below Girujan Top

Figure-10: sweetness extracted 20ms below Girujan Top

Figure-11: Mono-frequency plot extracted @ 12Hz, 20ms below Girujan Top
Fig-14, 15 and 16 shows the RGB colour blend plots at 12, 20 and 30Hz below 20 ms of Girujan Top (zone of interest) extracted using FFT, CWT & matching pursuit spectral decomposition methods. The lowest frequency is represented by red color, medium frequency to the green and the highest frequency into the blue color characterized by RGB blending of above three frequencies. White color shows the high amplitude at above three frequencies while black color shows the low amplitude at all the frequencies. Generally, we are interested in white color where amplitude from these three frequencies is the maximum. These white patches may be interesting in hydrocarbon point of view. Figure-17 shows the improved vertical resolution using FFT, CWT & MPD. In purview of these analyses, it is very important to wisely choose the spectral decomposition method to bring out the distribution pattern of thin sands.

The study clearly demonstrates the comparison of FFT, CWT & MPD methods. The probable channel feature is clearly illuminated in RGB blended volumes as white color, which was not visible in other two volumes. (Figure-14, 15 and 16).
Conclusion:

This is a case study, which gives the practical usage of spectral decomposition methods for delineation of geological features such as probable channel in the study area. The results obtained from three spectral methods were compared. It is evident from the comparison that improvement of vertical resolution is seen in MPD with respect to FFT & CWT. These results are well corroborating with the RMS amplitude extracted within the zone of interest, which shows the validity and strength of MPD. Further RGB blending of spectrally decomposed mono-frequencies @12 Hz, 20 Hz & 30 Hz with MPD, is done and probable channel features/geometries are illuminated better compared to individual components of frequency analysis. Preservation of frequency content and better vertical resolution, which is a key parameter in any spectral decomposition analysis, is achieved through this workflow. The methodology presented in the study can be useful in the areas having geological complexity and heterogeneity.

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