MULTI-COLOR DISPLAY OF SPECTRAL ATTRIBUTES

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Current spectral decomposition techniques typically generate a suite of tightly sampled instantaneous spectral attribute volumes (Castagna et al., 2003; Liu and Marfurt, 2005; Partyka et al., 1999). While there is a great deal of useful information included in these instantaneous spectral attribute volumes, it is not easy for seismic interpreters to inspect each one of them individually. Typical volumetric analysis will generate between 10 and 100 output volumes of both magnitude and phase, which can easily fill up the limited disk space available on an interpretation workstation. As a partial solution to this challenge, Liu and Marfurt (2005) combined peak frequency and peak amplitude to highlight channel systems. In this paper, we will discuss three different display techniques to delineate the fine structural patterns and the discontinuities. The first technique simply animates through single frequency volumes and is the simplest way to show spectral variation. The second technique is a composite plot of peak frequency, peak amplitude and coherence using a hue-lightness-gray colormap which is able to delineate both lateral discontinuities and vertical changes in thickness in a single image. The advantage of such a composite image is that the peak frequency can indicate the thin bed thickness variations, while coherence can detect the discontinuities. The composite plot of phase at peak frequency can also show discontinuities. While several workers have co-rendered three spectral components by plotting the against Red-Green-Blue (RGB) color model components, the optimum choice of these frequencies is not clear. We partially circumvent this problem by
using RGB to display the coefficients of three predetermined basis function. When added together, these coefficient-weighted basis functions approximate the computed spectrum in a least-squares sense. This plot method provides moderate details of the full spectrum. More important, instead of outputting 100 different single spectral components, we can display a single RGB volume. Stork (2006) showed similar RGB plot technique, which he called as ColorStack. Different from our least-squares fitting method, he summarized the frequency ranges from 1 to 100 Hz to three different groups which are defined as RGB values. We use ocean bottom cable data from the Louisiana Shelf, Gulf of Mexico to test the three color plot techniques, in order to convey the spectral information.

**Plotting techniques**

Spectral attributes can be viewed in different ways. We will list three different methods to plot spectral attributes. The most popular plot method is to directly view single spectral components. After time-frequency decomposition, a 3-D seismic volume can be decomposed in a suite of single frequency volumes, so we can directly view these single frequency volumes through 3-D visualization and try to find the changes among single frequency volumes. The second plot method is to statistically represent the spectrum with a few parameters. We find that composite volumes of peak frequency (or phase at peak frequency), peak amplitude above average and coherence attributes to be particularly useful. Other workers propose estimating the spectrum by its bandwidth and kurtosis, though we have seen little published in this area. However they are computed, the main advantage of a composite plot is that we only have one 3D
 composite volume to investigate. Coherence attributes can detect the structure discontinuities while the peak frequency can predict vertical variations in thickness. The third plot method of representing 100 or more spectral components is to use Red-Green-Blue (RGB) to display sub spectral estimates of the data using predetermined basis functions. The following is the detail of RGB plotting.

First of all, we define three different basis functions which represent Red, Green and Blue (RGB) functions (Figure 1). We have chosen three simple raised cosine basis functions with a well-defined center frequency.

![Figure 1. Red, Green and Blue basis functions.](image)

The equation we used to describe RGB functions is:

\[
\text{Basisfunction} = 0.5 \cdot (1.0 + \cos(\pi \frac{f - f_{\text{RGB}}}{k \cdot f_{\text{Bandwidth}}}))
\]

(1)
Where $f_{\text{RGB}}$ means the center frequency for Red, Green and Blue functions, $f_{\text{Bandwidth}}$ is the frequency bandwidth of the input seismic data, and $k$ is constant value.

From equation 1, we can define different RGB functions when we give different RGB center frequencies and bandwidth values. After we define the three RGB basis functions, we use least-squares solutions to match the coefficients of our three basis functions to the instantaneous frequency amplitude at each time location. These three coefficients are mapped directly against Red, Green and Blue in readily-available display algorithms. Figure 2 demonstrates the least-squares fit coefficients of our three basis functions of an instantaneous frequency amplitude spectrum (Black line). The maximum amplitude values of Red, Green and Blue dash-lines are RGB coefficients. Figure 3 shows one examples of RGB plot on one synthetic trace. Figure 3b is the time frequency distributions of input synthetic trace (Figure 3a). Figure 3c is the least-squares fit of the RGB basis functions of the time frequency distributions shown in Figure 3b. Figure 3d is the final RGB plot of the three RGB coefficients displayed in Figure 3c. By exploiting the well-established color mixing model, it's easy for an interpreter to associate red with a lower frequency, green with a middle frequency, and blue with a higher frequency. Likewise, most interpreters know that cyan falls between blue and green, yellow between green and red, and then a bi-modal spectrum of low and high frequencies will appear as magenta. Flat spectra will appear as shades of gray. Least-squares RGB plot has the same advantage as composite plot of peak frequency, peak amplitude and coherence. Based on the decomposed time-frequency distributions, we can reduce the plot volume to the same size as input seismic
volume. Unfortunately, our simple RGB plot can only display the gross behavior of the finely sampled spectrum. For more details, we need look though the single frequency volumes.

Figure 2. Red, Green and Blue coefficients calculated by least-squares fit with instantaneous frequency distribution.

Figure 3. (a) Synthetic trace; (b) time-frequency distribution of (a); (c) Red, Green and Blue coefficients of least-squares fit of (b); (d) RGB plot of (c).
**Field examples**

The field data used for color displays is from the Louisiana Shelf, Gulf of Mexico, U.S.A.

**Single frequency volume plot**

We used a wavelet based time-frequency decomposition method described by Liu and Marfurt (2005) to decompose seismic data into a suite of 80 single frequency volumes ranging between 10 and 90 Hz. Figure 4 shows the input seismic volume. The 30 Hz volume in Figure 5 is representative of the data quality. Black arrows point to a meandering channels. Since channels may have different spectral response than the neighboring matrix, different single frequency volumes will in general delineate or highlight different thickness channels.

![Figure 4. Seismic volume.](image-url)
Composite plot of spectral attributes and coherence

We will generate two multi-attribute volumes using composite color-maps. The first composite volume is a combination of peak frequency, peak amplitude and coherence attributes. Figure 6 shows the composite volume generation flow by combining peak frequency, peak amplitude and coherence attributes (the time slice at 2.220 second). Figure 6a, 6b and 6d gives the time slice of peak frequency, peak amplitude and coherence. Figure 6c is the initial composite volume of peak frequency and peak amplitude. Combining peak frequency and peak amplitude, we can easily find the frequency variation at strong amplitude. Figure 6e demonstrates the final composite volume of peak frequency, peak amplitude and coherence. The advantage of the composite plot shown in Figure 6e is that both structural discontinuities and bed thickness are shown in a single image. Coherence attributes can detect discontinuities, while
peak frequency indicates the bed thickness changes. Bright (higher lightness) colors indicate a highly tuned (non flat) spectrum. A higher peak frequency (a red hue) indicates a thinner layer, while a lower peak frequency (a blue hue) indicates a thicker layer. The yellow channel indicated by white arrows in Figure 6e is tuned in at 50 Hz. The red arrow points to the fault (Figure 6e).

Figure 6. Composite volume plotting. (a) time slice of peak frequency; (b) time slice of peak amplitude; (c) time slice of composite volume of peak frequency and peak amplitude; (d) time slice of coherence; (e) time slice of composite volume of peak frequency, peak amplitude and coherence. (time slice at 2.220 second)
The second composite volume is a combination of phase at the peak frequency, peak amplitude above background and coherence attributes. Taner, Koehler and Sheriff (1979) stated that instantaneous phase may indicate the discontinuities. After time-frequency decomposition, we also compute a suite of phase as well as amplitude volumes at each frequency. In Figure 7 only phases at the peak frequency are used to generate our composite volume. Comparing Figure 6e and 7, we note that the sinuous channel at the upper left of figures is shows up in both figures. Figure 7 shows the channel because of different phase information compared to the background response, while in Figure 6e the channel and background have different frequency tuning.

Figure 7. Time slice of composite volume of phase at peak frequency, peak amplitude and coherence at 2.220 second. The magenta channel has a -90 degree phase, consistent with thin bed tuning.

**Red-Green-Blue plot**

We are now ready to apply our least-square Red-Green-Blue basis function technique to the same data volume. Figure 8 shows the process of RGB display on a 2-D line seismic data. Figure
8a is a vertical section through the seismic data. A red arrow indicates a known gas reservoir. The single frequency sections are shown in Figure 8b which only include 8 different frequencies from 10 to 80 Hz. The Red-Green-Blue curves which represent three basis functions are shown in Figure 8b. After using least-squares fitting on these three different basis functions with decomposed frequency values, we get the Red, Green and Blue sections shown in Figure 8c, 8d and 8e. The final RGB plot is given in Figure 8f. A white arrow points to the red zone which indicates a low frequency. Figure 9 demonstrates the time slice of RGB plot at 2.220 s. Comparing Figure 9 and Figure 6e, our RGB plot just displays only moderate frequency changes.

Conclusions

We have applied three different color display techniques to a suite of 80 spectral components in attempt to summarize key information in a single image. The direct color plot of single frequency volume is the simplest way to view decomposed frequency attributes, but given time constraints, it is generally infeasible for a seismic interpreter to view all the frequency volumes. The alternative composite color display of peak frequency, peak amplitude and coherence can highlight the discontinuities and thickness variation. The third Red-Green-Blue plot can represent the moderate frequency changes of seismic data. Both composite color plot and RGB plot can save seismic interpreter time to view spectral attributes quickly and can be considered as the first step to display instantaneous spectral attributes.
Figure 8. Red-Green-Blue plotting technique. (a) seismic section; (b) single frequency slices; (c), (d) and (e) are Red, Green and Blue values calculated by three basis functions; (f) RGB plot of (c), (d) and (e).
Figure 9. Time slice of Red-Green-Blue plot at 2.220 second.


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