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Phase decomposition using matching pursuit

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Summary

This study presents a new approach to phase decomposition using the matching pursuit algorithm. We first review the traditional approach to phase decomposition, which involves decomposing an input seismic trace into a number of phase segments based on the maxima and minima found on the instantaneous amplitude envelope of the trace and then assigning these segments to the dominant phase of each segment found using the instantaneous phase value at the peak of the envelope in each segment. We then describe the theory of our new method which involves applying the matching pursuit algorithm to the complex trace pair, consisting of the real trace and the imaginary trace found using the Hilbert transform. We then illustrate these two methods using two synthetic examples and a stack over a Cretaceous gas sand from Alberta.

Theory and Workflow

This study was motivated by the paper entitled "Phase Decomposition" by Castagna et al. (2016). Castagna et al. (2016) first discuss several approaches to spectral decomposition, which involve decomposing a seismic trace into its individual frequency components. This creates a time-frequency gather $S'(f, t)$. The stack of this gather, which can be written

$$S(t) = \int S'(f,t)df \ , \tag{1}$$

will recreate the seismic trace $S(t)$ with its accuracy depending on the algorithm and number of frequencies used. Castagna et al. (2016) then propose creating a time-phase gather $S'(\theta, t)$, where θ indicates phase. The stack of this gather, which can be written

$$S(t) = \int S'(\theta,t)d\theta \ , \tag{2}$$

will again recreate the seismic trace $S(t)$ with its accuracy depending on the algorithm and number of phase values used. Although Castagna et al. (2016) show examples of spectral decomposition and discuss instantaneous amplitude and phase, they do not go into details about how to compute the phase decomposition gather. However, the paper by De Abreu, Castagna and Gil (2019) does give the details of the algorithm, which are as follows:

1. Input a seismic trace $S(t)$ and compute its Hilbert transform $H(t)$, instantaneous amplitude envelope $A(t)$ and instantaneous phase $\theta(t)$, where:

$$A(t) = \sqrt{S(t)^2 + H(t)^2} \text{ , and} \tag{3}$$

$$\theta(t) = \tan^{-1}\left[\frac{H(t)}{S(t)}\right]. \tag{4}$$

2. Identify the peaks and troughs on the amplitude envelope and divide the seismic traces into segments defined by successive troughs.
3. At each peak on the amplitude envelope, identify the dominant phase using the value found at the instantaneous phase.
4. Create a blank seismic gather with a fixed number of phase traces (for example: -180°, -90°, 0°, 90°, or a finer increment).
5. Assign the segments found on the seismic trace to these phase traces based on the value of the instantaneous phase at each segment.

The algorithm described in point 3 above is based on an algorithm developed by Russell and Liang (1980) from an idea first presented by Thompson (1979) and given at an internal Chevron conference. In this approach, the instantaneous amplitude and phase of the cross-correlation between seismic traces taken from intersecting lines in a 2D survey. The time shift to the peak of the correlation envelope and the instantaneous phase at the peak were then used as time and phase shifts to tie the two lines. The algorithm was published by Bishop and Nunns (1994).

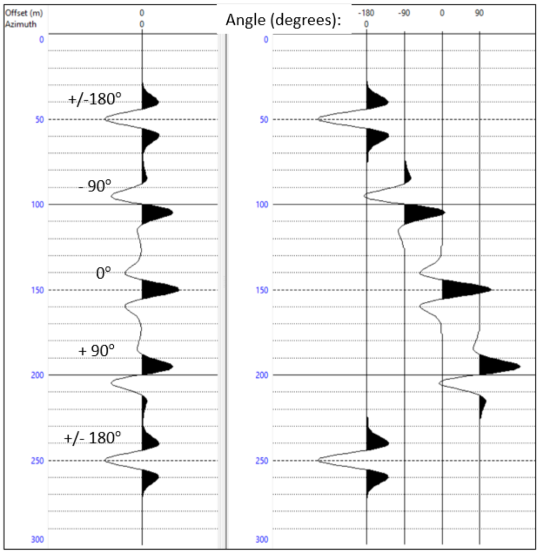
In the new algorithm proposed in this study, a complex trace is computed from the seismic trace and its Hilbert transform. A suite of complex Ricker wavelets is then computed over a range of phase values. Next, the matching pursuit algorithm (Mallat and Zhang, 1993) is used to identify equivalent phase wavelet segments in the complex seismic trace and these seismic segments are assigned to their correct time locations on a phase gather.

In the next section we will look at several synthetic examples and a real data example from Alberta.

Results

Our first example was inspired by a paper entitled “Phase decomposition and its applications” by Chopra et al. (2022). In that paper, the authors create a 300 ms long synthetic trace consisting of five Ricker wavelets with the same dominant frequency, 40 Hz, and different phase values of +/-180°, -90°, 0° and 90°. We recreated this trace as shown in Figure 1(a), where the +/-180° wavelets are at 50 and 250 ms, the -90° wavelet is at 100 ms, the 0° wavelet is at 150 ms and the 90° wavelet is at 200 ms. The phase decomposition of this trace is shown in Figure 1(b), where the wavelets have been decomposed into four constant phase traces at +/-180°, -90°, 0° and 90°. Note that the algorithm cannot distinguish between -180° and +180° since these values both wrap around at the same phase value.

Obviously, the synthetic shown in Figure 1 is quite a simple trace upon which to perform phase decomposition since the individual phase segments are well separated using the amplitude envelope, and each of the dominant phase values is clearly identified using the instantaneous phase at the peaks of the envelope.



(a) (b)

Figure 1. (a) A synthetic trace consisting of five Ricker wavelets of phase +/-180, -90, 0 and 90 degrees, and (b) the phase decomposition of this trace.

Our second synthetic example is shown and Figure 2 and is a classic wedge model. The full wedge is shown in the upper left panel, and phases of, -90°, 0°, 90°, and 180° are shown in the other panels. The algorithm has done a good job in separating the various phase values.

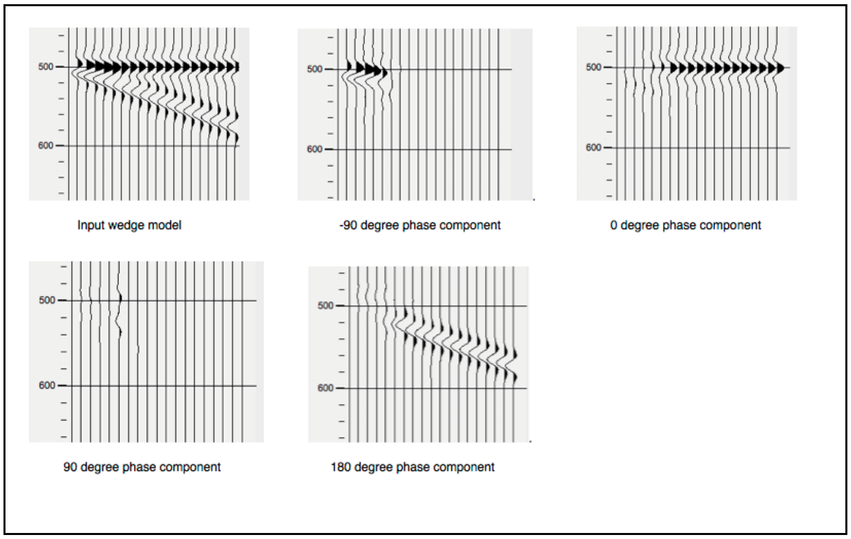
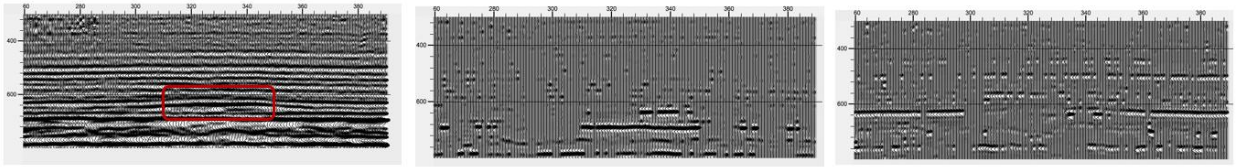


Figure 2. A synthetic wedge model, where the model is shown in the upper left, and the four phase panels are also shown.

Finally, we apply the algorithm to a Cretaceous gas sand example from southern Alberta, shown in Figure 3. The stack over the gas sand is shown in Figure 3(a), where the gas sand anomaly is shown by the red box. Figures 3(b), 3(c), 3(e), and 3(f) show the 0°, -90°, 90°, and 180° phase components, and Figure 3(d) shows the reconstruction of the stack computed by summing the four phase components. Note that the gas sand zone is clearly identified in figure 3(b) and that figure 1(d) shows that the stack has been almost perfectly reconstructed.


(a) Full Stack (b) 0° Phase Component (c) -90° Phase Component

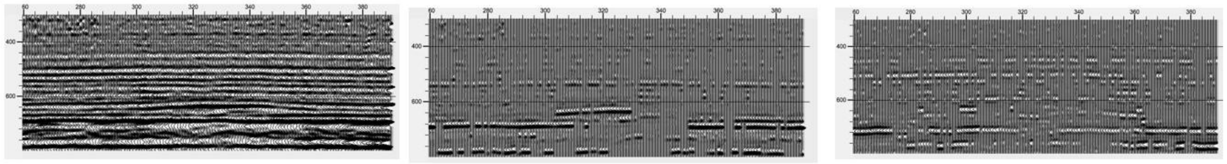

(d) Sum of components (e) 90° Phase Component (f) 180° Phase Component

Figure 3. Phase decomposition applied to a gas sand example from Alberta, where the gas sand zone is identified by the red box in (a) and has been clearly identified in by the 0° phase component.

Conclusions

In this study we presented a new approach to phase decomposition using the matching pursuit algorithm. We first reviewed the traditional approach to phase decomposition and then described the theory of our new method, which involves applying the matching pursuit algorithm to the complex trace pair consisting of the real trace and the imaginary trace found using the Hilbert transform. We illustrated these two methods using two synthetic examples, a simple trace consisting of five constant phase Ricker wavelets and a wedge model, and a stack over a Cretaceous gas sand from Alberta. When applied to the gas sand stack, the phase decomposition method was able to clearly identify the gas sand.

Novel Information

Although the phase decomposition method was developed initially in 2016, we have developed and applied an new approach to the method that involves a combination of instantaneous attributes and the matching pursuit method.

Acknowledgements

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