Attribute-Assisted Footprint Suppression with LoG filter

Tengfei Lin, University of Oklahoma; Bo Zhang, University of Alabama; Kurt J Marfurt, University of Oklahoma

Summary

Acquisition footprint often poses a major problem for 3D seismic data interpretation. Ideally, footprint from acquisition can be processed through more careful attention to trace balancing statics, noise reduction, and velocity analysis (Hill et al., 1999; Gülünay, 2000). Such reprocessing is not feasible on many legacy data volumes where the pre-stack data cannot be found or no longer exists. Seismic attributes often provide an effective means of delineating subtle geological features of interest such as channels, small faults, and fractures, but can also enhance acquisition footprint. For this reason attributes can be used to both design and evaluate the effectiveness of alternative footprint suppression workflows. We show that the application of the Laplacian of a Gaussian Filter deserves an obvious improvement for the filter results.

Introduction

The footprint suppression tool is actually a processing workflow using k_x-k_y filters and adaptive subtraction. k_x-k_y filters are routinely used in the image processing industry to remove structured noise, either periodic or aperiodic, that contaminates pictures or maps. Following the previous arguments we consider data volumes along a horizon slice, time slice, or local horizon slice but restrict ourselves to an *S* by *R* sample rectangular analysis window. Filters can be designed as a function of the wavenumber to remove coherent, periodic or aperiodic noise (Buttkus, 2000).

Since we are addressing legacy post-stack data volumes, no source or receiver geometry information is retained in the headers. Therefore, the first step is to generate footprint-contaminated attributes from seismic data. To estimate the noise, the footprint is enhanced and stratigraphic signal suppressed by applying a vertical median filter that removes the stratigraphic features. Along with rescaling the attribute amplitudes, a constant bias may need to be added to the attribute data to force noise-free (e.g. high coherence, *c*=1) values to be the same as null values in muted and dead trace zones. Once the footprint is enhanced, it is transformed to k_x-k_y space and smooth pedestal filters are generated that best represent the acquisition footprint in the seismic attribute volume. Parallel to the footprint characterization steps described above, the seismic amplitude volume is transformed to k_x-k_y space and masked with the pedestal filters generated from the attribute data. The reverse transform of the masked amplitude data yields modeled noise time or horizons slices that are then adaptively subtracted from the original data to produce filtered seismic data. Finally we unslice the filtered seismic data. Footprint sensitive attributes are computed from the filtered data to QC the filtering process and decide whether the data need more filtering or is ready for interpretation. The figure from Falconer and Marfurt (2006) shows the detailed workflow for this process (Figure 1).

Theory

Laplace-Gaussian Filter (LoG):

Because the Laplace operator not only detects edges but also may enhance noise, it may be desirable to smooth the image first by a convolution with a Gaussian kernel of width σ:

$$G_\sigma(k_x,k_y) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot exp\left[-\frac{{k_x}^2+{k_y}^2}{2\sigma^2}\right], \qquad (1)$$

Transforming to the k_x-k_y domain:

$$LoG_\sigma(k_x,k_y) = \frac{1}{\pi\sigma^2} \cdot \left[1-\frac{k_x^2+k_y^2}{2\sigma^2}\right] exp\left[-\frac{k_x^2+k_y^2}{2\sigma^2}\right]. \qquad (2)$$

After transforming the attribute slice from *x*-*y* domain to the k_x-k_y domain, we obtain the magnitude $m(k_x,k_y)$ and phase $\varphi(k_x,k_y)$. Then we filter the magnitude slice $m(k_x,k_y)$ using the Laplacian of a Gaussian filter $G_\sigma(k_x,k_y)$, to obtain the filtered magnitude slice $m_{filt}(k_x,k_y)$.

Weighted Factor:

From the magnitude slice after k_x-k_y filter, we can found that the values far away from the center (large k_x, k_y values zone) are significantly smaller than those in the center part of the signal. We can multiply these images by a weighting factor, $w(k_x,k_y)$, to better enhance the response.

$$w(k_x,k_y) = exp\left(\frac{|k|}{|k|_{max}}\right), \qquad (4)$$

where

$$|k| = \left(k_x^2+k_y^2\right)^{1/2},$$

$$|k|_{max} = max\left(\left(k_x^2+k_y^2\right)^{1/2}\right).$$

$$m_{filt}(k_x,k_y) = G_\sigma(k_x,k_y)\, w(k_x,k_y) m(k_x,k_y) \qquad (5)$$

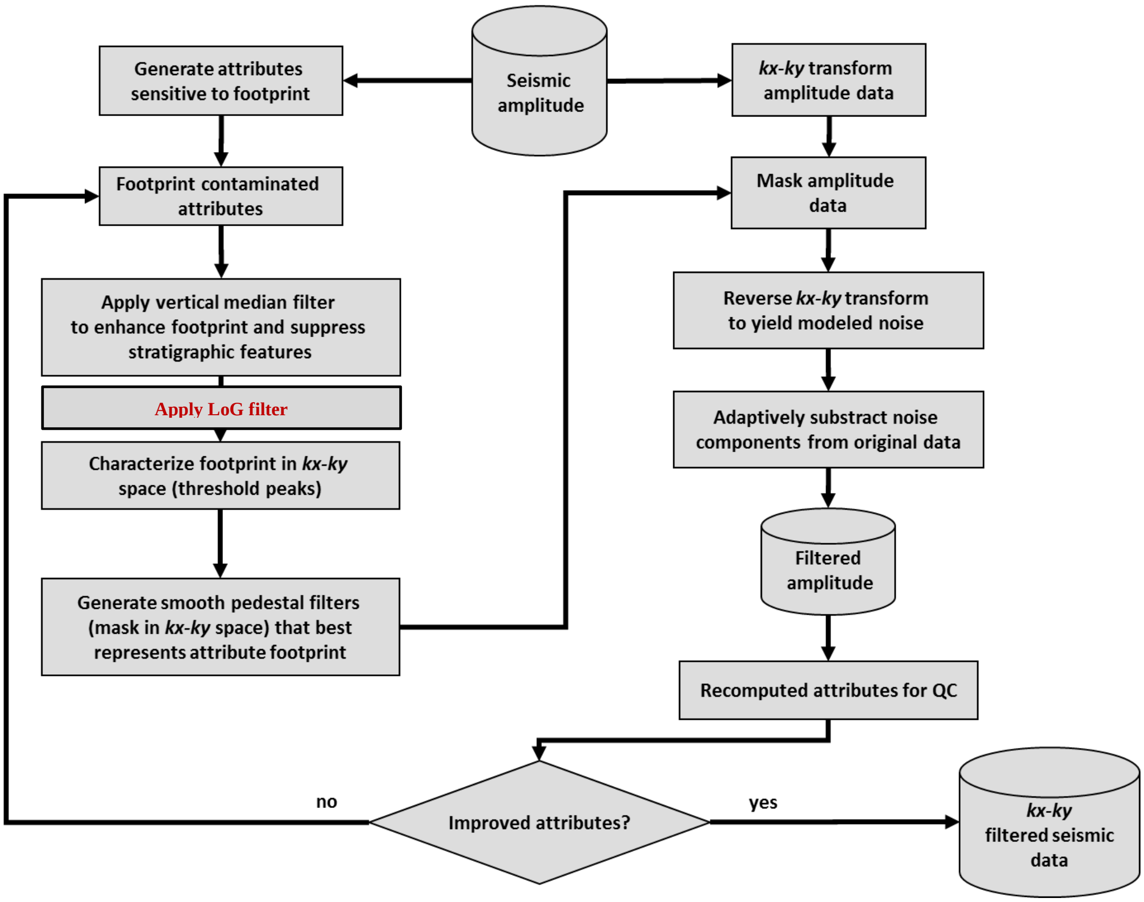

Figure 1. Falconer and Marfurt's (2006) attributed-assisted footprint suppression workflow showing the increases of a LoG and balancing filter.

Applications

We apply the footprint suppression workflow shown above to a seismic amplitude volume acquired over the Delaware Basin, NM. The post-stack seismic volume holds high data quality but is overprinted by strong footprint noise in the shallower zones. The pre-stack seismic data are unavailable, which means the acquisition footprint noise cannot be attacked using conventional seismic processing workflows, such as improved statics, high-resolution velocity analysis, ground roll attenuation, and 5D interpolation.

Figure 2a indicates a time slice through seismic amplitude at t=0.6 s. Red arrows point out footprint anomalies on the data. Figure 2b shows the corresponding time slice through energy ratio similarity exacerbating short wavelength footprint anomalies. A median filter suppresses vertical stratigraphic, dipping faults, and enhances vertical footprint features (Figure 2c).

Figures 2d and e show time slices through energy ratio similarity at t=0.6 s in the k_x-k_y domain before/after the application of the LoG filter, respectively. White arrows indicate peak amplitude anomalies due to the footprint signal in the attribute. Black arrows indicate N-S and E-W anomalies that correlated to the survey edges as well as footprint. The real amplitude anomalies due to the footprint are clearer in Figure 2e than the ones in Figure 2d. Therefore, we are going to apply anomalies of k_x-k_y domain in the following workflow.

Figures 2f and g indicate the time slice through seismic magnitude as well as seismic phase at t=0.6 s in the k_x-k_y domain, respectively. Most of the smooth, relatively flat signal will cluster near the origin (yellow arrows) whereas lineaments such faults and channels will be scattered at larger values of k_x-k_y. White arrows indicate zones where noise clusters are present. Black arrows indicate anomalies due to the survey edges. The notch filter pedestals before/after the application of the LoG filter in Figures 2h and i, respectively, will be used to model the noise components. Noise (white arrows) will then be adaptively subtracted from the data for a noise reduced seismic amplitude volume. Note more pedestals (red arrows) are detected after LoG filtering.

Figure 3 indicates time slices at t=0.6 s through: (a) original seismic amplitude data, k_x-k_y filtered seismic amplitude data (b) before and (c) after the application of the LoG filter. Most of the N-S and E-W lineaments and localized low amplitude "spots" present marked by red arrows due to the footprint in the original data in Figure 3a have been partly removed in Figure 3b, which are indicated by orange arrows. In addition, the application of the LoG filter in Figure 3c perfectly subtracts these "spots", and enhances the real geologic features.

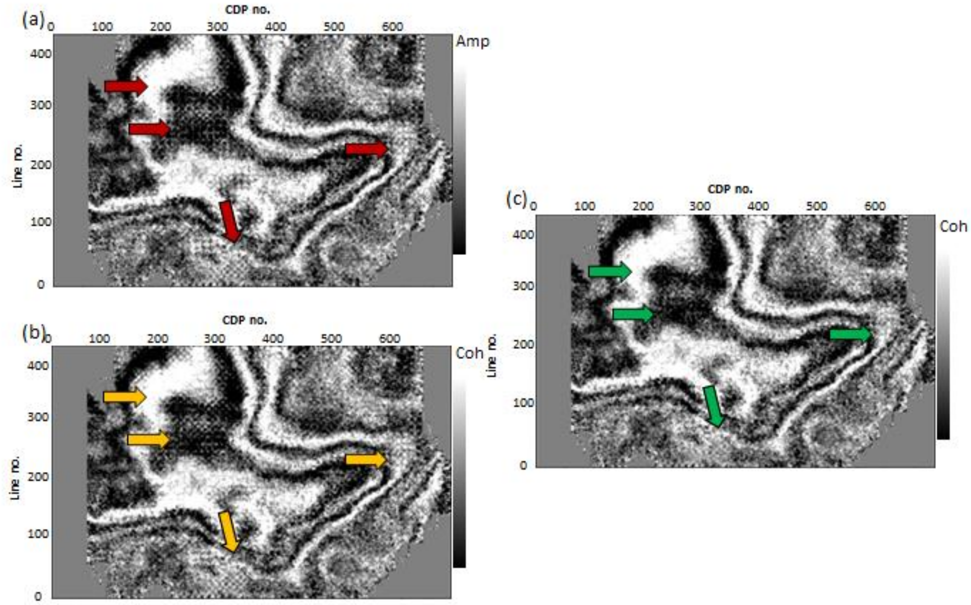

Figure 3. Time slices at t=0.6 s through: (a) original seismic amplitude data, (b) k_x-k_y filtered seismic amplitude data and (c) k_x-k_y filtered seismic amplitude data after the LoG filter.

Conclusions

Footprint noise due to the acquisition suppresses stratigraphic features, and generates artifacts that can be confused with faults and fractures.

The effectiveness of delineating subtle geological features of interest such as channels, small faults, fractures, and acquisition footprint enable seismic attributes to characterize footprint that can be used to define notch filters.

The application of Laplacian of a Gaussian Filter in the k_x-k_y domain sharpens the parodic footprint pedestals facilitates subsequent thresholding, and hence filter design.

Acknowledgements

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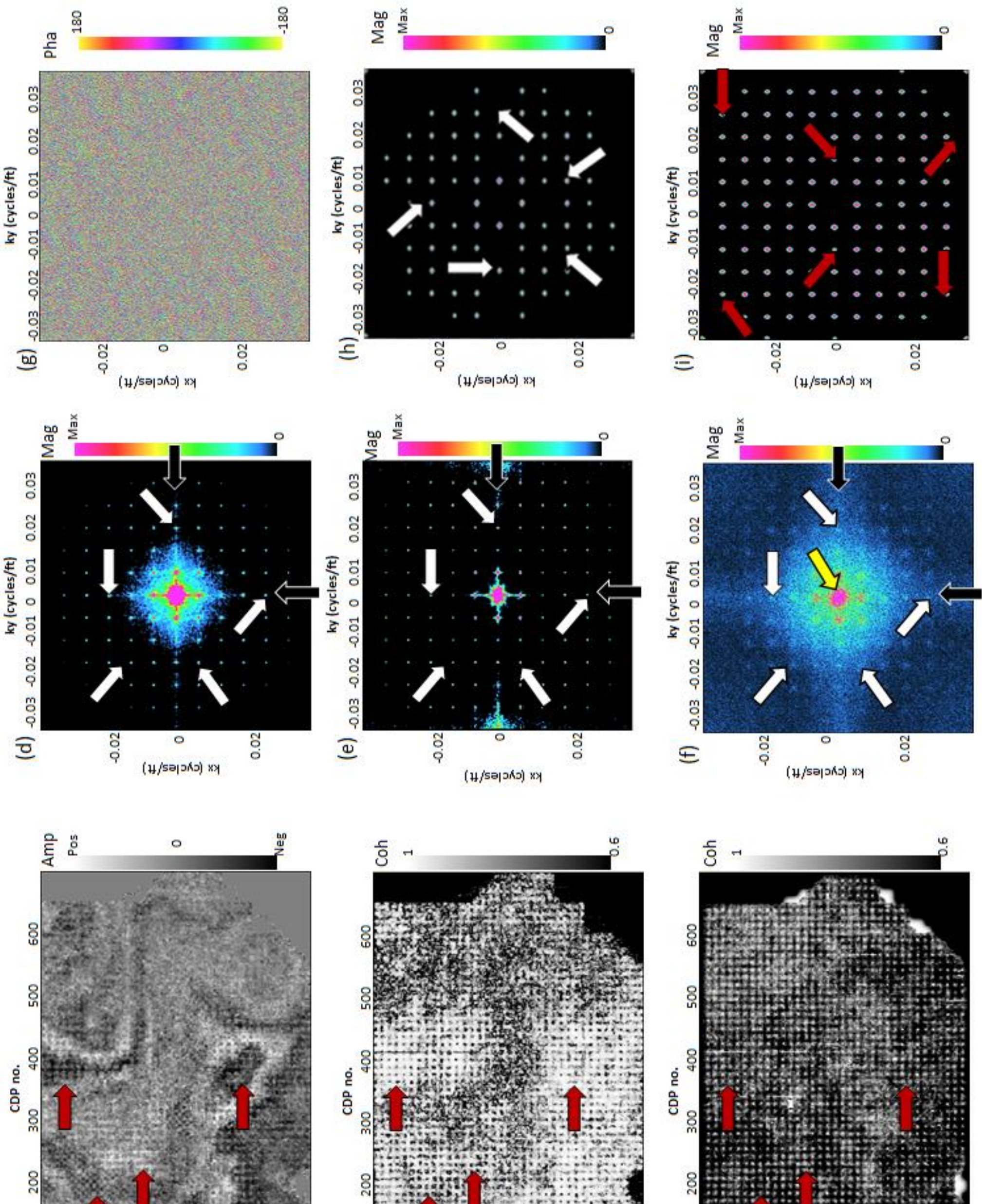

Figure 2. (a) Time slice through seismic amplitude at t=0.6 s. Red arrows indicate footprint anomalies in the data. (b) Corresponding time slice through energy ratio similarity exacerbating short wavelength footprint anomalies. (c) Time slice through smoothed energy ratio similarity at t=0.6 s after vertical median filtering to suppress geologic features and enhance vertical footprint features. (d) Time slice through energy ratio similarity at t=0.6 s in the k_x-k_y domain before the application of the LoG filter. White arrows indicate peak amplitude anomalies due to the footprint signal in the attribute. Black arrows indicate N-S and E-W anomalies that correlated to the survey edges as well as footprint. (e) Time slice through energy ratio similarity at t=0.6 s in the k_x-k_y domain after the application of the LoG filter. (f) Time slice through seismic magnitude at t=0.6 s in the k_x-k_y domain. White arrows indicate zones where noise clusters are present. Black arrows indicate anomalies due to the survey edges. (g) Time slice through seismic phase at t=0.6 s in the k_x-k_y domain. (h) and (i) are notch filter pedestals before and after the application of the LoG filter, respectively. Note more pedestals are detected after LoG filtering.

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