Multi-orientation footprint attenuation using co-ordinate rotations on 3D data.

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Summary

Several effective footprint removal filtering techniques assume that the footprint orientations are parallel to the co-ordinate axes of the filter; but when they are not, those techniques may fail. A direct rotation of the data volume in order to line up the footprint orientation with the co-ordinate axes for filter operation, and rotating it back to the original orientation will involve two re-binning processes. Data rotation introduces errors due to imperfect interpolation methods in practice. Given this fact, in this paper, we will try to minimize those errors by only estimating the footprint in the rotated co-ordinates, and rotating it back to be removed from the original unrotated input data.

Introduction

It is common to describe a footprint as an undesirable pattern with a linear 'fabric' look that appears in a time or depth section of a 3D seismic volume. A footprint can be generated by acquisition inadequacy, uneven fold distribution, mute pattern, or processing artifacts such as those from interpolation or migration. Such causes will affect all sorts of 3D data, land or marine, and therefore a footprint attenuation filter is in order (Marfurt et al., 1998). In the past, there have been a few methods developed to remove interfering footprints. One of the methods takes advantage of the fact that when a 2D spatial Fourier transform is applied to a time slice section with a footprint pattern that is aligned parallel to any binning co-ordinate axis, the footprint will be transformed and localized into the high spatial frequency locations along the k_x, k_y axes. Judging from the footprint spacing apparent in the time slice x-y domain, a simple narrow band suppression filter is applied on the axes in the k_x-k_y domain of that time slice t (Drummond et al., 2000; Satinder and Larsen, 2000); here we will call it a t-k_x-k_y filter. Another method is to apply a dip filter in the ω-k_x-k_y domain of the post stack cube (Marfurt et al., 1998). Both methods are simple and effective but they require that the footprint orientation be aligned with the binning coordinates of the filter; otherwise, the methods cannot perform properly. One of the other methods that does not assume the axes orientation is a reduced-rank type of SVD application in the time slice by time slice bases - It can be used to eliminate footprints (Al-Bannagi et al., 2005), but there is no guarantee that the fine details of the geology will not also reside at higher-rank where the footprint is located. So in such a case, separating the two becomes a compromising effort.

In this paper, our contribution is to improve those footprint removal filters that have an orientation requirement, and we will use a t-k_x-k_y filter just as an illustration where the footprint orientation is not aligned with the binning axes. Since any data rotation on the time slice data t-x-y involves a rebinning interpolation, the process is generally lossy because an ideal interpolation algorithm is still under quest, and consequently, interpolation may smooth out complex geological details. However, it is less demanding for an interpolator to fit a footprint pattern that is linear in nature which is narrow in spatial frequency bandwidth, than to fit geological details that are not linear, more 'random' in nature which is broad in spatial frequency bandwidth. So we propose to estimate the footprint by itself in the rotated co-ordinates and then rotate it back to the original orientation so that it can be subtracted from the data in order to minimize any loss of geological details.

Theory and Method

The objective is to recover a footprint free time slice $p(x,y)$ at t from $d(x,y)$ a time slice of the input 3D data volume interfered by footprint $u(x,y)$ that has an orientation angle $-\phi$ with respect to one of the axes. Either axis is fine as long as it is kept consistent. $R_\phi[\cdot]$ is a generic rotation rebinning operator. Here as an example, we simply used a 2D linear interpolation in space for illustration purposes. The recovery method is as follows:

Step 1. Rotate the data volume with an angle ϕ to align with the axes yielding

$$d_\phi(x,y) = R_\phi[d(x,y)], \tag{1}$$

and then apply a 2D spatial FFT on eqt. (1) giving $D_\phi(k_x,k_y)$.

Step 2. Estimate the footprint free data $p_\phi(x,y)$ in the rotated co-ordinates by applying a t-k_x-k_y filter $H_\phi(k_x,k_y)$ to $D_\phi(k_x,k_y)$ followed by a 2D spatial inverse FFT operation:

$$p_\phi(x,y) = IFFT[H_\phi(k_x,k_y) \bullet D_\phi(k_x,k_y)]\,. \tag{2}$$

Step 3. The estimate of the footprint in the rotated co-ordinates becomes

$$\begin{aligned} u_\phi(x,y) &= d_\phi(x,y) - p_\phi(x,y) \\ &= IFFT[D_\phi(k_x,k_y)/H_\phi(k_x,k_y)] \end{aligned}\,. \tag{3}$$

Step 4. Unrotate the estimated footprint described in eqt. (3) with an angle $-\phi$ back to the original orientation producing an estimated footprint model:

$$\bar{u}(x,y) = R_{-\phi}\left[u_{\phi}(x,y)\right]. \tag{4}$$

Step 5. Remove the estimated footprint model from the original input data yielding a footprint free result:

$$p(x,y) = d(x,y) - \bar{u}(x,y). \tag{5}$$

This result $p(x,y)$ in eqt. (5) may not be the same as simply unrotating the footprint free estimate in eqt. (2) i.e.

$$\bar{p}(x,y) = R_{-\phi}\left[p_{\phi}(x,y)\right] \tag{6}$$

unless both $R_{\phi}[\cdot]$ and $R_{-\phi}[\cdot]$ are lossless rebinning operators. We are going to show $p(x,y)$ typically better preserves geological details than $\bar{p}(x,y)$. It is because of the fact that in eqt. (5), the footprint estimate has gone though two rebinning errors, whereas in eqt. (6) the signal estimate has gone through two rebinning errors. Although there are errors in both cases, the error in interpolating the narrow bandwidth linear footprint estimate is generally smaller than the error in interpolating the broad bandwidth complex geological estimate, as mentioned above.

Example 1

The objective of this example is to show how a footprint that is not aligned with the natural binning axes can be removed by the two approaches described in eqt. (5) and eqt. (6), and to compare their results.

Figure 1 (a) is an input time slice of a migrated volume contaminated with a strong footprint pattern whose orientation does not align with any binning axes. The orientation angle ϕ is -45 degrees from the y-axis.

Figure 1 (b) shows the footprint attenuated output according to eqt. (6), the direct approach, giving a smoothed result losing some geological details.

Figure 1 (c) is the unrotated footprint estimate described in eqt. (4) to be removed from the input data figure 1 (a) to give the final footprint attenuated result shown in figure 1 (d).

Figure 1 (d) is the footprint attenuated output according to the proposed eqt. (5). The result reveals finer geological details when compared to figure 1 (b).

Example 2

The purpose of this example is to illustrate how the proposed filter performs when there are multiple footprint patterns with different orientations that are not aligned to the natural binning axes.

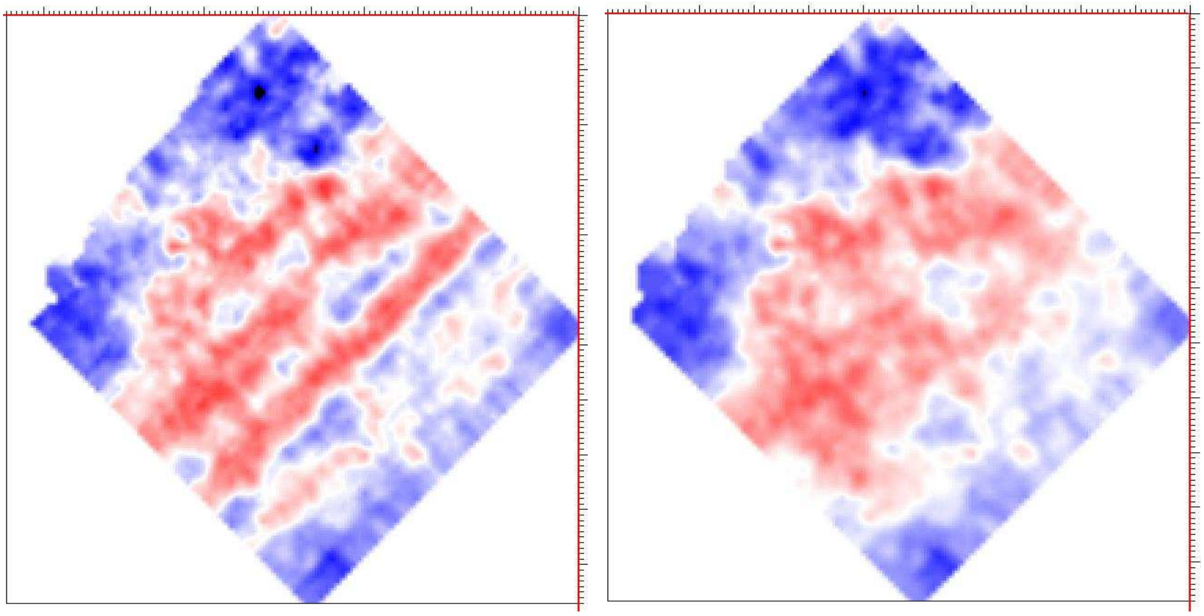
Figure 2 (a) is an input time slice of a single migrated merged volume, where the volume is a merged data set of a few individual surveys with different orientations. It shows distinct conflicting footprint patterns.

Figure 2 (b) is the footprint attenuated output using the proposed method after three application sequences from step 1 to step 5, with three sets of rotation angles ϕ of -20, 10 and 45 degrees. It shows that the result is a much more interpretable geological section when compared to the input figure 2 (a).

Figure 2 (c) is the difference plot with a gain factor of 2X showing that footprints of various orientations have been removed without the presence of geological features.

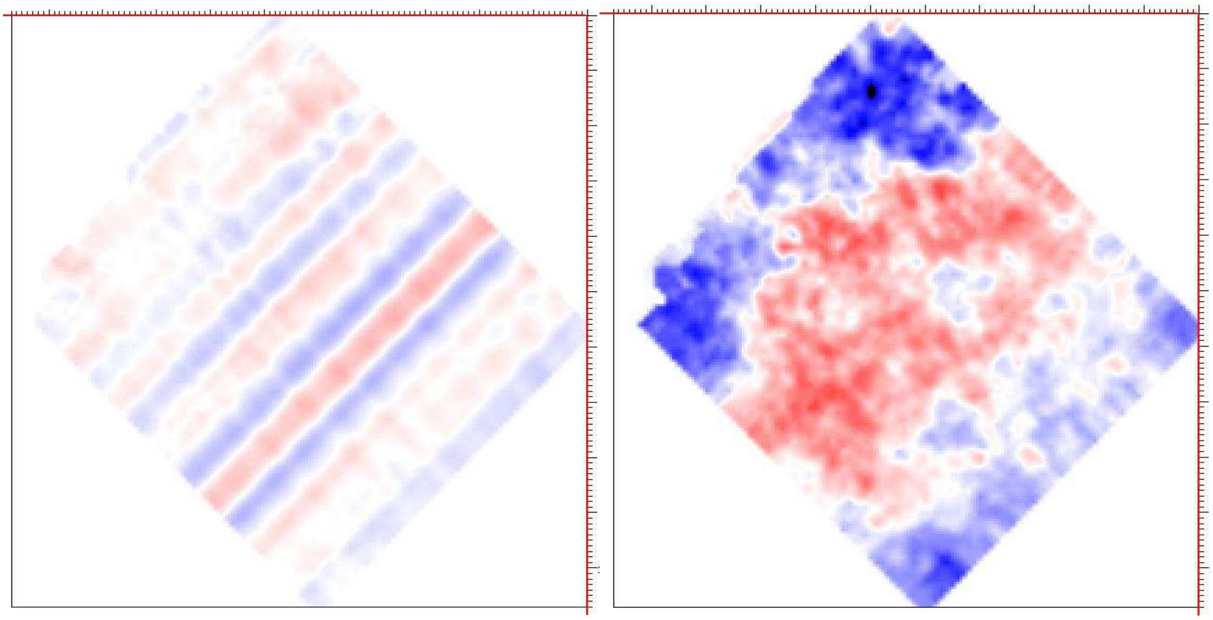
Conclusions

For those footprint removal methods that require the footprint orientation to align with the binning axes, we have illustrated a way to minimize signal loss due to rotation errors that come from imperfect interpolation during rebinning. This can be achieved by only estimating the footprint in the rotated co-ordinates, and rotating it back so that it can be subtracted from the original unrotated input data.



(a) Input data *d(x,y)*: with a strong footprint pattern whose orientation does not align with the natural binning axes.

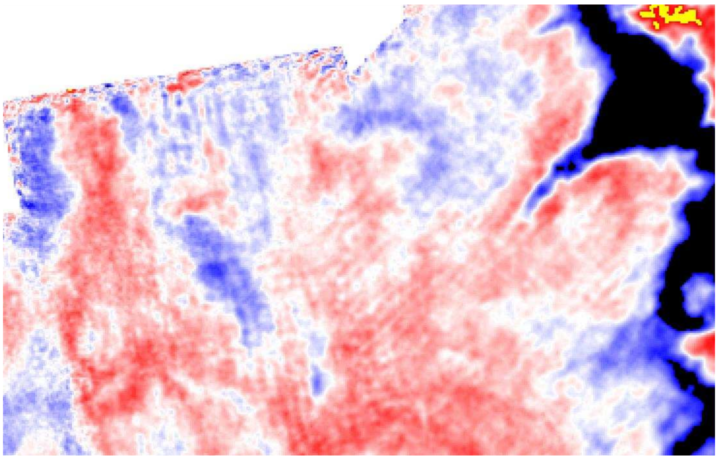
(b) Footprint attenuated output $p(x, y)$ according to eqt. (6) showing smoothed geology and loss of fine details.



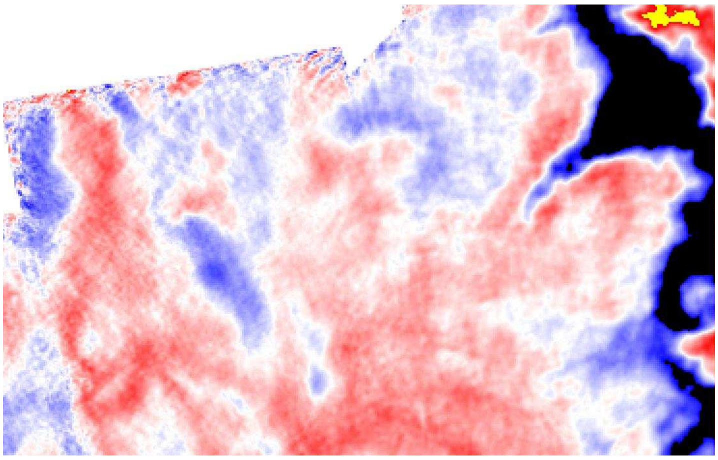
(c) Unrotated footprint estimate $\bar{u}(x, y)$ according to eqt. (4) to be subtracted from input data (a) to give a result (d).

(d) Footprint attenuated output $p(x, y)$ according to eqt. (5). showing sharp geological details.

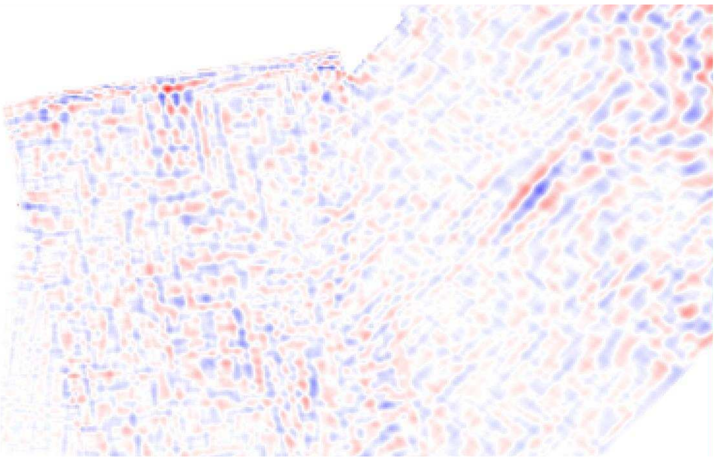
Figure 1. Time slice of a real data set with footprint orientation (ϕ = -45 deg from y-axis) not aligned with the binning axes.



(a) Input time slice of a migrated volume:
Footprint patterns are observed.



(b) Output time slice:
Footprint attenuation has been applied to (a) with three different application orientations (ϕ = -20, 10 and 45 deg from y-axis).



(c) The difference plot:
i.e. the input (a) subtract the output (b). A gain factor of 2X is applied to show that footprints of various orientations have been removed without the presence of geological features.

Figure 2.Time slice of a real data set from a few merged surveys with multiple footprint orientations.

EDITED REFERENCES

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