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Footprint Removal with Co-ordinate Rotation

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Summary

Some of the 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

A footprint is 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 migration artifacts. 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 axes, the footprint will be transformed 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 filter is applied on the axes in the k_x-k_y domain of that time slice t (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.

The contribution of this paper 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 subsequently, interpolation may smooth out complex geological details. However, it is less demanding for an interpolator to fit the footprint pattern that is linear than to fit geological details that are not linear and more 'random' in nature. 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/or Method

Let *d(x,y)* be a time slice at *t* of the input 3D data volume interfered by footprint *u(x,y)* that has an orientation angle $-\phi$ with respect to the axes. The objective is to recover a footprint free time slice *p(x,y)*. $R_\phi[]$ is a generic rotation rebinning operator. The recovery method is as follows:

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

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

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

$$u_\phi(x,y) = d_\phi(x,y) - p_\phi(x,y) = IFFT[1/H_\phi(k_x,k_y) \bullet D_\phi(k_x,k_y)] . \tag{3}$$

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 $R_\phi[]$ and $R_{-\phi}[]$ are lossless rebinning operators. We are going to show $p(x,y)$ typically better preserves sharp 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 linear footprint estimate is generally smaller than the error in interpolating the complex geological estimate as mentioned above.

Examples

The purpose of these examples is to show how a footprint that is not aligned with axes can be removed by two approaches described in eqt. (5) and eqt. (6) and to compare their results.

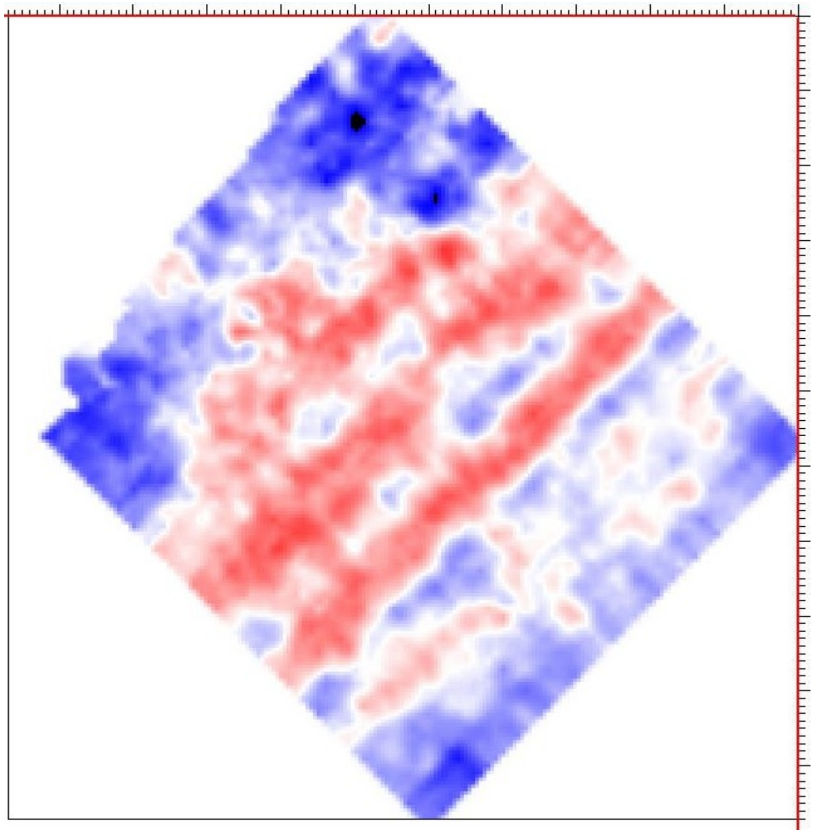

Figure 1: Input data *d(x,y)*: a moderately shallow time slice with a strong footprint pattern whose orientation (ϕ = 45 deg) does not align with the natural binning *x-y* axes.

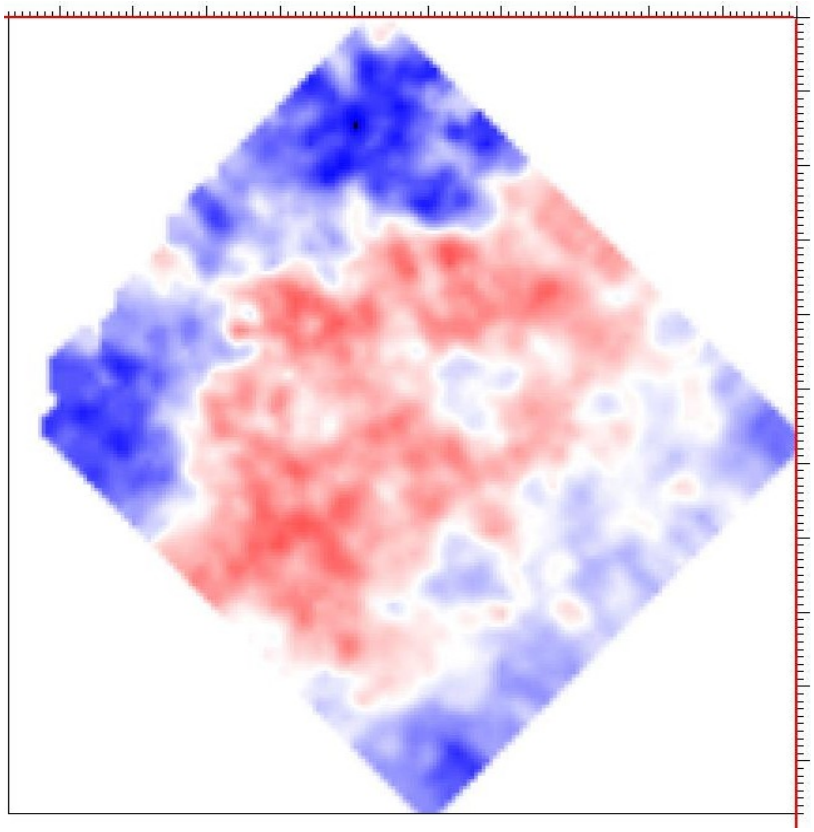

Figure 2: Footprint attenuated output $\overline{p}(x,y)$ according to eqt. (6). It is simply achieved by unrotating the footprint free estimate obtained in the rotated coordinates. Although the footprint is removed, the geologic details are smoothed out when compared to figure 3.

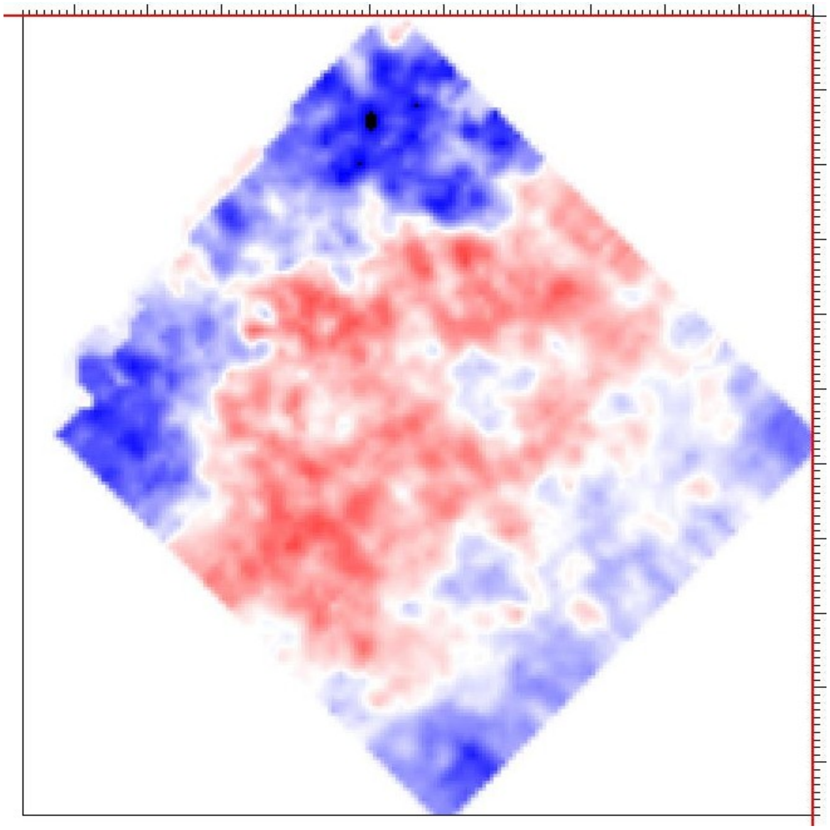

Figure 3: Footprint attenuated output $p(x, y)$ according to eqt. (5). It is achieved by un-rotating the footprint estimate obtained in the rotated coordinates, and then subtracting it from the original data. This gives a sharper image by maintaining the geological details when compared to figure 2.

Figure 1 is an input time slice contaminated with a strong footprint pattern whose orientation does not align with any binning axes. Figure 2 shows the footprint attenuated output according to eqt. (6) giving a blurred result. Figure 3 shows the footprint attenuated output according to the proposed eqt. (5) giving a sharp result.

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 interpolations 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.

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