geoconvention Virtual Event September 21-23 2020
CSPG • CSEG • CWLS • GAC • MAC • IAH

Pre and post-stack image deblurring through least-squares Kirchhoff

Tiago Alcantara, Elena Polyaeva, Eric Frugier, Cyrille Reiser and Bruno Virlouvet
PGS

Summary

Image deblurring techniques have been widely used in medical imaging to ensure reliable diagnostics on a variety of health conditions including cancer and brain anomalies (Debnath et al., 2013, Agarwal et al., 2017, and Nolte et al., 2020). The goal is to reconstruct the true image using information about the distortion operator (point spread function), and an initial representation of the object. Recently, increased compute power has enabled deblurring to become a hot topic in the seismic industry, as it can compensate for acquisition limitations and propagation effects, resulting in high-resolution seismic images that can minimize drilling risks and aid reservoir characterization. We present an image-domain, pre and post-stack least-squares Kirchhoff implementation, to generate high-resolution images suitable for quantitative interpretation.

Introduction

Kirchhoff depth migration is still the mainstay algorithm in many regions of the world. This method provides cost-effective high-resolution images with amplitude fidelity. Though very robust, the amplitude and resolution are still impacted by propagation effects and variable illumination. Least-squares migration can overcome these limitations by posing imaging as an inverse problem (Nemeth et al. 1999).

In this case study, an image-domain least-squares Kirchhoff is applied to a deep water seismic dataset from offshore Canada. Both pre and post-stack inversions were performed. Inverted offset domain common image gathers (ODCIGs) are compared to prestack depth migration data to demonstrate consistent AVO fidelity. Additionally, a post-stack inversion is presented to show the benefits to vertical and lateral resolution from least-squares migration.

Image domain Kirchhoff least-squares migration

Conventional imaging methods can produce an accurate structural image, but reflectivity may be blurred. This is because migration is the adjoint of the modeling operator. Consequently, this assumption may limit resolution and affect amplitude integrity of the seismic data. Least-squares migration is a technique that can overcome these issues by treating imaging as an inverse problem. A variety of techniques exists in the seismic industry ranging from data-domain implementations (Lu et al., 2017) to image-domain approaches (Valenciano, 2008).

While the data-domain approaches minimizes the difference between modeled and observed data in an iterative process, the image-domain methods works as a multidimensional deconvolution of the migrated image based on the system response, also known as point spread function (PSF).

The inversion starts with the PSF calculation, a two-step process of modeling and migration using a series of discrete point scatters (reflectivity), acquisition geometry and an accurate velocity model. The computed PSF are the iteratively used to deconvolve the system response from the migrated image. During this process, only the reflectivity model is updated while the velocity model remains unchanged.

Figure 1 shows an example of a migrated (Figure 1A) and an inverted (Figure 1C) point scatter model with their respective Fourier pair, frequency-wavenumber (Figure 1B and 1D). Least-squares migration broadens the frequency-wavenumber (FK) spectrum, resulting in a higher resolution image.

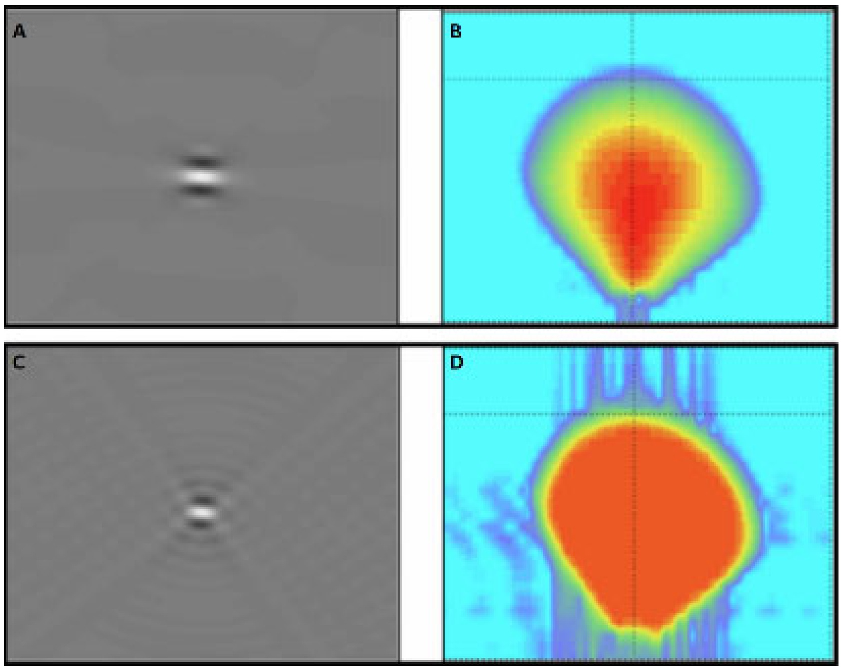

Figure 1. Migration (A) is the convolution between the Hessian matrix of the velocity model with a point scatter (reflectivity). Least-squares migration (C) deconvolves the point spread function from the migrated image resulting in a more detailed representation of the earth's reflectivity. The Fourier pair (B and D), indicates that inversion broaden the FK spectrum (Valenciano, 2015).

Kirchhoff least-squares implementation and results

For this case study, the Tablelands 3D data around the Great Barasway well was used. This is a PGS-TGS joint venture acquisition with 16 multisensor streamers, 100 m separation, and 8 km streamer length. The input to both pre and post-stack inversions were premigrated common offset gathers, Kirchhoff depth migrated raw gathers, a post-processed stack, and an accurate velocity field derived from full waveform inversion (Frugier et al., 2020).

In order to perform the prestack inversion, a multidimensional PSF volume was generated (Valenciano et al., 2019) and deconvolved from the ODCIGs. The inversion improved resolution and preserved the AVO response at the Great Barasway F-66 well location (Figure 2). Due to the presence of residual coherent noise in the data, the deconvolution process boosted noise in the Tertiary section, as presented in the relative Vp/Vs ratio (Figure 3).

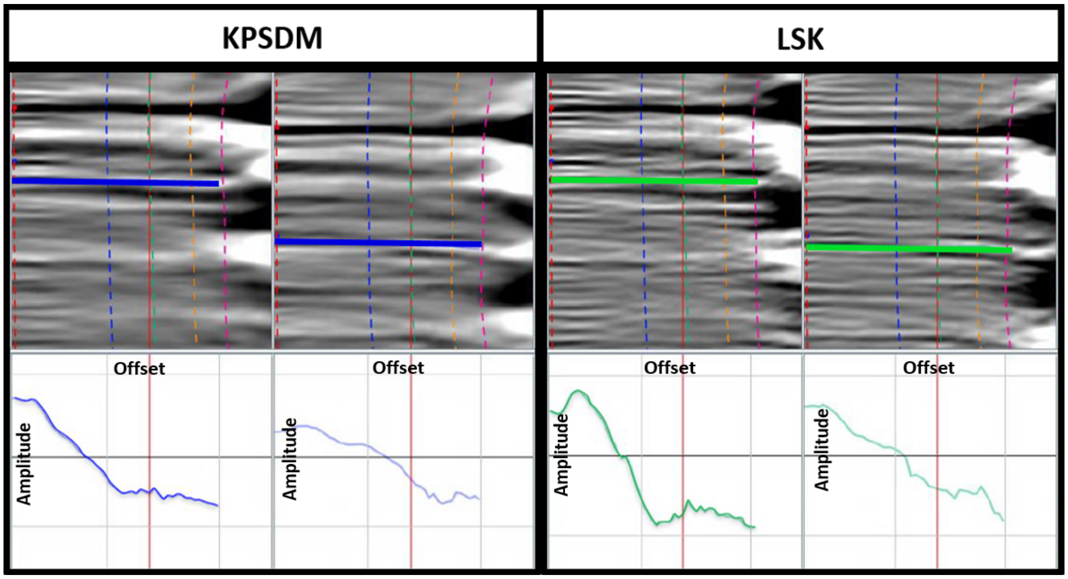

Figure 2. KPSDM and LSK offset domain common image gathers. Least-squares Kirchhoff (LSK) improves resolution and preserve the amplitude versus offset response.

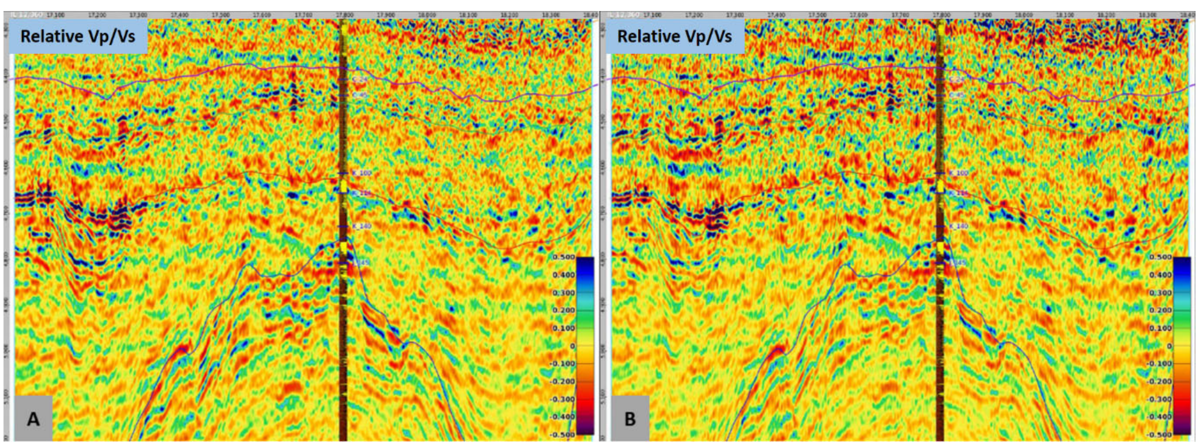

Figure 3. Vp/Vs ratio on Kirchhoff prestack depth migration (A) and least-squares Kirchhoff (B). The results are consistent with additional noise in the inversion caused by coherent noise present in the input data.

In order to avoid image degradation caused by noise in the input data, a noise attenuation step was required. A post-stack least-squares migration was performed using a stack with noise attenuation applied, and the Kirchhoff LSM improved vertical resolution and sharp boundary definition without boosting noise (Figure 4). Both amplitude (red dashed rectangle) and FK (yellow dashed rectangle) spectra were extracted to quantitatively confirm the resolution improvement given by the method. Kirchhoff LSM broadens the FK spectra and flattens the amplitude spectrum.

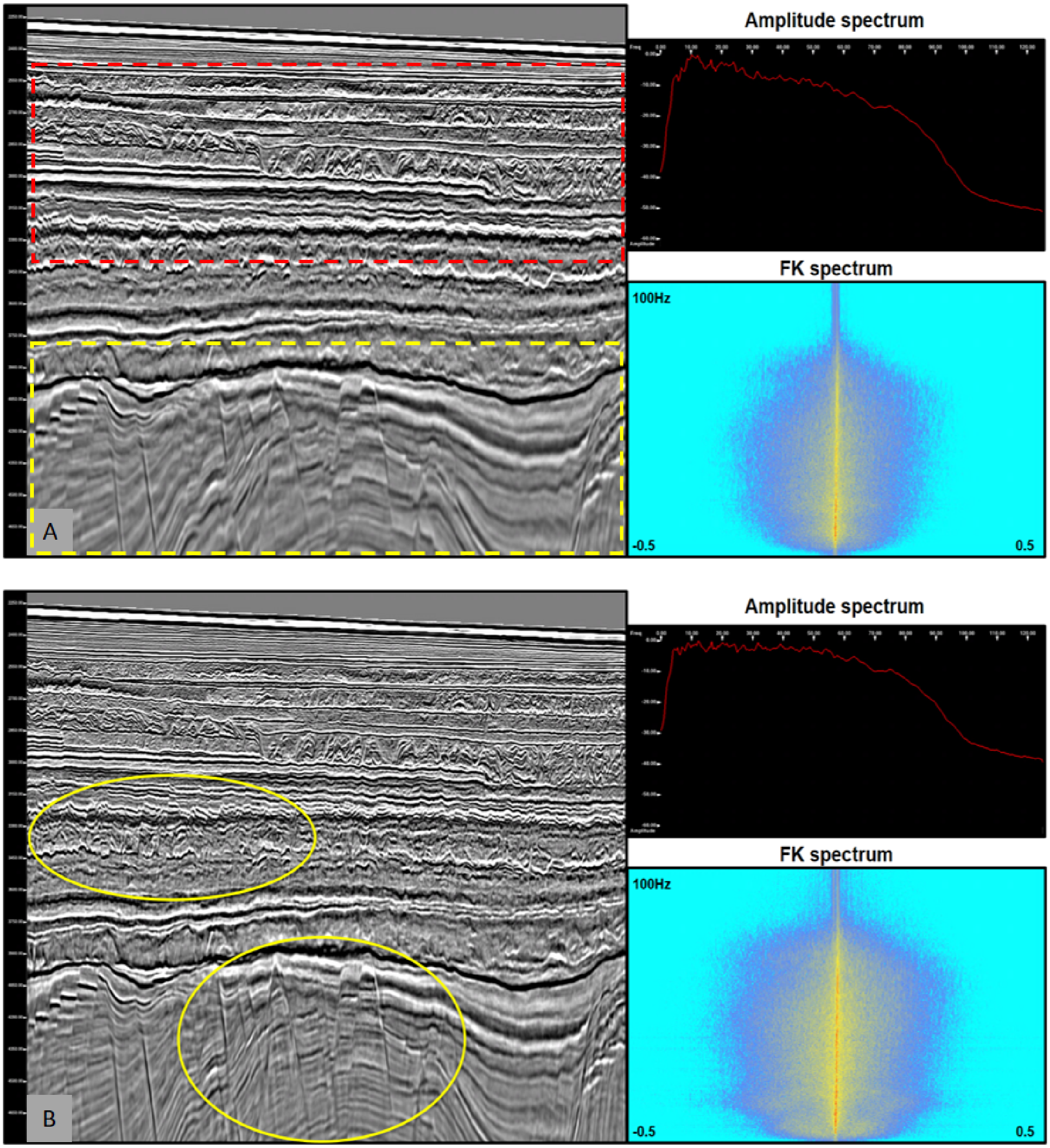

Figure 4. Kirchhoff depth migrated stack (A) and least-squares Kirchhoff (B). Inversion improves vertical resolution resulting in a flatter amplitude spectrum (red dashed rectangle). Additionally, it does improve sharp boundary imaging such as faults and, consequentially, broaden the FK spectrum (yellow dashed rectangle).

Conclusion

Pre and post-stack deblurring through image-domain least-squares Kirchhoff was successfully applied offshore Canada. Prestack inversion showed improved resolution and a consistent AVO response with Kirchhoff and depth migration. The relative Vp/Vs indicated that residual coherent noise was boosted by the deconvolution process. To avoid image degradation during the deblurring process, noise attenuation is necessary. In order to support this, a post-stack inversion was performed using an image with noise attenuation applied. Least-squares migration improved resolution with no consequence to noise levels. We have demonstrated that least-squares Kirchhoff migration can provide both high-resolution data, and AVO compliant prestack gathers, that can mitigate exploration risks and aid reservoir characterization.

Acknowledgements

We thank PGS-TGS joint venture for permission to publish this work. Furthermore, we thank Sam Brown, Chaoguang Zhou, Seongbok Lee, Paul Feldman, and Gina Sitaraman for the support and valuable discussions.

References

- Agarwal, S., Singh, O., and Nagaria, D. 2017. Deblurring of MRI Image Using Blind and Non-blind Deconvolution Methods. Biomedical and Pharmacology Journal, 10(3), 1409-1413.
- Debnath, A., Rai H., Yadav C., and Agarwal A., 2013. Deblurring and Denoising of Magnetic Resonance Images using Blind Deconvolution Method. In Journal of Computer Applications vol. 81, 7-12.
- Frugier, E., Alcantara, T., Virlouvet, B., Montevecchi, N., Cameron D., and Wright, R., 2020. High-resolution Full Waveform Inversion model building in deep-water environment: A case study in the Orphan basin. Abstract under review. GeoConvention.
- Lu, S., X., Li, A. A., Valenciano, N., Chemingui, and C., Cheng, 2017. Least-Squares Wave-Equation Migration for Broadband Imaging: 79th Annual International Conference and Exhibition, EAGE, Extended Abstracts.
- Nemeth, T., C., Wu, and G., Schuster, 1999. Least-squares migration of incomplete reflection data: Geophysics, 64, 208–221.
- Nolte T., Gross-Weege N., Doneva M., Koken P., Elevelt A., Truhn D., Kuhl C., and Schulz V., 2020. Spiral blurring correction with water-fat separation for magnetic resonance fingerprinting in the breast. Magnetic Resonance in Medicine 83 (4), 1192-1207.
- Valenciano, A. A., 2008. Imaging by wave-equation inversion: Ph.D. thesis, Stanford University.
- Valenciano, A.A., S., Lu, N., Chemingui, and J., Yang, 2015. High-resolution imaging by wave equation reflectivity inversion: 77th Annual International Conference and Exhibition, EAGE, Extended Abstracts.
- Valenciano, A.A., Orlovich, M., Klochikhina, E. and Chemingui, N., 2019 Least-Squares Wave Equation Migration With Angle Gathers. 81th EAGE Conference and Exhibition.