Improving seismic resolution via warping deghosting

Eduardo Filpo F. da Silva (Petrobras)*, Gilberto Lima (Petrobras) and Marina C. Anibal (Petrobras).

Abstract

In this article, we present the warping-deghosthing method as a tool to obtain outstanding gain of resolution with an enhancement in the bandwidth of amplitude spectra, in special in the low frequency range. The method is based on the idea that each ghost component of the recorded signal is a deformed version of the primary reflection. Under this consideration, the deghosting procedure becomes an inverse problem, in which the warping operator is used to model all ghost components.

The methodology can be applied in conventional marine streamer dataset using only information routinely available and it does not require any special source-receiver configuration.

We present the strategy of removing ghost effect via warping in three steps: i) time-shift computation, ii) solution of the warping-deghosting system, and iii) refinement of the initial solution.

The method is applied in both conventional and broadband datasets. The first example is a conventional near trace section from the Santos basin, Brazil. The method was applied using nominal parameters without any previous processing and using just nominal information. The deghosting boosts the bandwidth, in special on the low-frequency range. In the second example, the warping deghosting method successfully removes the source side ghost present in a broadband time-migrated section.

Introduction

Conventional marine streamer data suffers from a reduction of the useful bandwidth caused for the presence of undesired ghost effect. The ghost effect is a superposition of time-delayed seismic reflections. Besides the primary reflected energy that travels from the source to the receiver, the recorded signal contain three components generated by extra reflections at the free surface.

The idea of addressing the ghost problem in marine data via additional measurements of the reflected wavefield has been investigated since the fifties by Haggerty (1956). Multi-component acquisition systems are available not only to ocean-bottom cable and to nodes, but to towed cable (Carlson et al. 2007; Robertson et al. 2008). Although the significant evolution of acquisition systems associated with special deghosting processing techniques, the existing legacy data justify research on deghosting methods for conventional streamer marine data.

Filpo and Lima (2014) introduced the present warping deghosting method, in which the desired signal is obtained as a solution of an inverse problem. This approach does not require special acquisition geometry and uses only single seismic measurements. The method is based on the idea that each ghost component of the recorded signal is a deformed version of the desired signal, which is free of ghost effects. This idea is valid under the premise of absence noise and direct wave, which is the same used by Beasley et al. (2013). In order to model the deformations related with the ghost effects, the warping algorithm requires the knowledge of water velocity, source and receiver depths.

Filpo et al (2015) present several examples of application of warping deghosting in both pre and post-stack datasets in time and tau-p domain. Those results demonstrate the robustness and the flexibility of the method.

Method

Figure 1 illustrates the ghost problem and the proposed approach. For simplicity, we consider that the recorded seismic signal contains only two energy components: one related to the primary reflection, ray path in blue, and another to the receiver ghost, in red. As these two signal components are very similar in shape, we can consider each one as a deformed version of the other, and the recorded signal Y(t) may be represented by $Y(t) = S(t) - \alpha(t)S(t+\mu(t))$. Where S(t) is the desired signal, α(t) is a scaling factor function and μ(t) is the time-shift defined by the travel time difference between the ghost and primary reflections for each time. In matrix notation, the equation become $\mathbf{y} = (\mathbf{I} + \mathbf{W})\,\mathbf{s}$, where $\mathbf{W}$ is the warping operator responsible for the pulse deformation, and $\mathbf{I}$ is the identity.

In conventional marine acquisition, the source is not located at the free-surface and source ghost components are present at the recorded data, which has four components. In this case, the matrix representation of the recorded data is:

$$\mathbf{y} = (\,\mathbf{I} + \mathbf{W}_{\mathbf{s}} + \mathbf{W}_{\mathbf{r}} + \mathbf{W}_{\mathbf{sr}}\,)\,\mathbf{s}, \qquad (1)$$

with $\mathbf{W_s}$, $\mathbf{W_r}$, and $\mathbf{W_{sr}}$ representing warping operators for deformations related to ghost effects caused by the source, the receiver and both, respectively. In order to construct the warping operators, it is necessary to compute the deformation functions α(t) and μ(t) for each component. In practical applications, the free-surface reflection coefficient is close to -1 and the ratio between the primary and the ghost reflection coefficient is almost constant. Under this approximation, the scaling factor α can be assumed constant and equal to 1 or -1 depending on the trajectory of the ghost component.

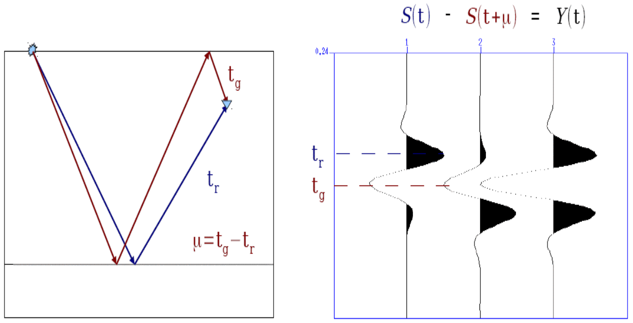

Figure 1: *Ghost illustration, μ is the travel time difference between the ghost and primary reflection.*

The present deghosting method comprises three steps. The first step is the travel time computation to define the time-shift function μ(t), which is used to construct warping operators. Travel time computation can be performed in several ways depending on the source-receiver distribution. In general, ray-tracing in 1D media gives satisfactory accuracy. The second step is to solve the warping-deghosting system given by equation (1). In our implementation, we solve it iteratively with a least square conjugate gradient algorithm. The last step corresponds to a refinement of the solution obtained at the first step. This refinement consists of decomposing the residue into four components and adding the free-of-ghost component to the initial solution.

Figure 2 illustrates the whole process using a synthetic seismic trace. The trace 1 is the input trace that suffers from the ghost effect and it corresponds to the vector **y** in warping-deghosting system (equation 1). The trace 2 is the first solution of this system and it is represented by the vector $\mathbf{s_0}$. This solution is obtained after a certain number of iterations that depends on the input trace and a given threshold value. Traces 3, 4 and 5 are the estimated ghost components, which are obtained by the application of each warping operator to the first solution vector $\mathbf{s_0}$. Trace 6 is the reconstituted input trace, which is obtained by the simple summation of traces 2,3,4,and 5, and it is represented by the vector $\mathbf{y_0}$. The difference between the input trace and the reconstituted trace gives us the residue vector **Δy** (trace 7). This residue still contains useful information and it also honors the warping-deghosting system, i.e., $\mathbf{\Delta y}=(\mathbf{I}+\mathbf{W_s}+\mathbf{W_r}+\mathbf{W_{sr}})\mathbf{\Delta s}$, where **Δs** is the free of ghost component of the residue. This component, trace 8, is obtained by solving the warping-system again, but using the trace 7 as input. On the right, we have an amplified version of these residue traces. The final solution **s**, trace 9, is obtained by the addition of traces 2 and 8.

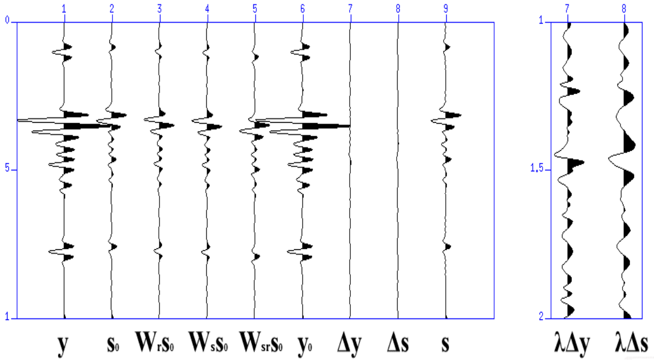

Figure 2: *1) Input trace, 2) first solution of the ghost-warping system for the input trace, 3) receiver ghost component, 4) source ghost component, 5) source-receiver component, 6) reconstituted signal (sum of all components) , 7) difference between the recorded data and the reconstituted data (residue), 8) free of ghost component of the residue, and 9) final solution*

Figure 3 illustrates the importance of the last step in the enhancement of bandwidth. The improvement obtained in this step is mostly on the low frequency range, where the ghost effect severe attenuates the original spectrum. In this example, the threshold residue decay used in the first inversion is 1%. In spite of this low amplitude signal, the impact in the recovered frequency spectrum is great. This strategy is much more stable than the option of directly invert the system with a smaller threshold residue. Another advantage of this strategy is that it permits to treat the residue before the second inversion. It is possible to remove undesirable effects introduced by the presence of noise and to better deal with imprecise source and receiver depths and of approximated time shifts.

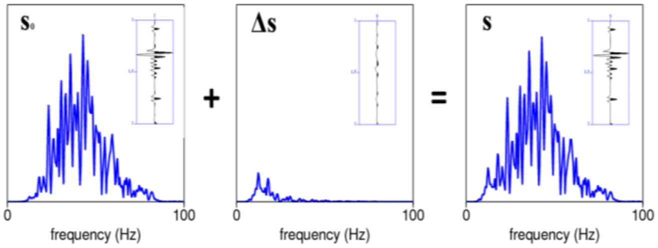

Figure 3: *On the left is the amplitude spectrum of the first solution, and on the centre, is the amplitude spectrum of the free-of-ghost component of the residue. On the right, is spectrum of the final solution.*

Examples

In this section, we present two examples of the application of the warping deghosting method. The first example is a near trace section from the Santos basin, Brazil. The method was applied using the nominal parameters, which are 275 meters for the offset, 7 meters for the source depth and the 9 meters for the receiver depth. The travel time computation for time-shift estimation considered a homogeneous velocity of 1500 *m/s*. The input sections has a time sample rate of 2 *ms* and does not suffer any kind of processing before the deghosting. Figures 4a and 4b show only the shallow part of the input section before and after deghosting respectively. Each Figure, 4a and 4b, also show its respective amplitude spectrum on the top-left corner. Observe that deghosting boosts the bandwidth, in special on the low-frequency range.

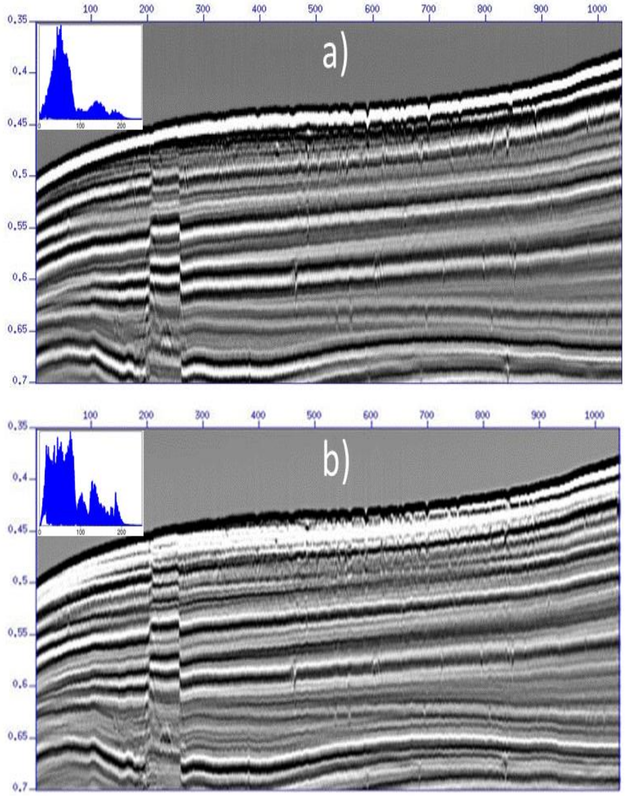

Figure 4*: Near trace sections: original section on the top, and after warping deghosting on the bottom.*

The second example corresponds to an application after migration in a broadband dataset. In this case, the input section has only the source side ghost component, and the warping deghosting was used to remove this ghost component. Figure 5 shows a comparison between the deghosting results of the proprietary tool and the warping deghosting. Obeserve that there is no visible difference between the two sections.

Conclusions

The method of deghosting via warping is based on a very simple theory, which assumes the premise that all ghost components can be obtained by deforming the desired component of the recorded data. The algorithm construction under this assumption is very simple, and works with conventional marine streamer data without using any extra information than that routinely available.

The method is applicable to broadband datasets as well, but only to treat the source side ghost.

The method works well in both, pre and post-stack datasets. Due its capability in working with imprecise information, this methodology is applicable to migrated images. Along the last two years, the method has been successfully used in several datasets on the shelf.

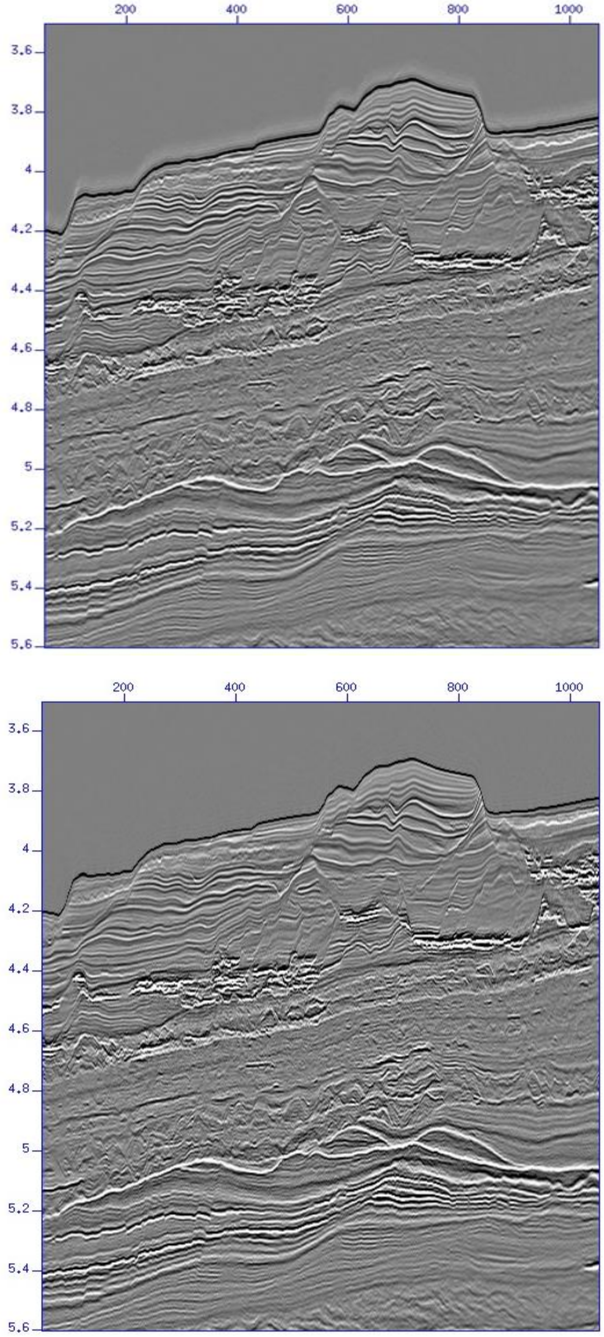

Figure 5*: Broadband time migrated sections after deghosting: proprietary solution on the top, and warping solution on the bottom.*

The method successfully remove ghosts in both broadband and conventional datasets. The results show an outstanding gain of quality of resolution with an enhancement in the bandwidth of amplitude spectra. These improvements, not only produces better images, but also more trustable inversion results.

Although we assume that the source and receiver depths are known, it is possible to use the warping approach to extract that information from the data itself. The construction of warping operators depends only on small time-shifts, which can be obtained in several ways, leading to a very flexible and robust algorithm.

Acknowledgments

We would like to thank Petrobras for permitting this publication.

References

BEASLEY, C., COATES, R., JI, Y., AND PERDOMO, J. 2013. Wave equation receiver deghosting: a provocative example. 83rd. SEG Annual International Meeting. Expanded Abstracts, 32, 4226-4230.

CARLSON, D., LONG A., SÖLLNER, W., TAIBTI, H., TENGHAMN, R., AND LUNDE, N. 2007, Increased resolution and penetration from a towed dual-sensor streamer. First Break, 25, (12), 71-77.

FILPO, E. and LIMA, G. 2014. Deghosting via warping, 2nd. EAGE/SBGF Workshop 2014 - Broadband Seismic. Expanded Abstract.

FILPO, E., LIMA, G., AND LOBO, P. 2015. On the application of warping deghosting. 14th International Congress of the Brazilian Geophysical Society. Expanded Abstract.

HAGGERTY, P. E. 1956. Method and apparatus for canceling reverberations in water layers. U. S. Patent 2,757,356.

ROBERTSSON, J., MOORE, I., VASSALO, M., ÖZDEMIR, K., D., MANEN, D., AND ÖZBEK, A. 2008. On the use of multicomponent streamer recordings for reconstruction of pressure wavefields in the crossline direction. Geophysics, 73, (5), A45-A49