On the application of warping deghosting

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Summary

In this article, we present three different strategies of removing ghost effects using the warping-deghosting algorithm in conventional streamer marine data, all of them assume that the source and receiver depth are known. The method assumes that each ghost component of the recorded signal is a deformed version of the desired signal, which is free of ghost recorded energy. The free of ghost signal can be transformed into each ghost component by applying a shift in time and a proper amplitude scaling. The superposition of deformations forms an equation system where the desired signal is unknown. An approximated solution is obtained using the conjugate gradient method with stop criteria based on the achievement of a threshold residue level. All the trace deformation involved in this CG-solution are carried out by a warping algorithm. The first strategy uses ray-tracing to compute traveltimes shifts between the ghost components, a pre-stack example of this methodology is presented. A velocity model is required in this case. The second approach consists on the application of the warping-deghosting technique in tau-p domain, only the knowledge of water-layer velocity is required. The third approach consist s of achieving the desired residue in two or more steps, applying some processing technique between each step. A poststack section is used to exemplify the last two strategies. The obtained results show considerable gains in the bandwidth, especially in the low-frequency content.

Introduction

Traditionally, conventional marine streamer data presents a reduction of the useful bandwidth due the presence of unwanted ghost effects. Ghost effects are time-delayed reflections from the sea surface at the vicinity of the source and receiver locations. Ordinary source and receiver depths vary from 6 to 8 meters and 8 to 12 meters, respectively. As consequence, the useful bandwidth is confined between 6 to 70 Hz, degrading quality of seismic inversion.

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 nodes, but also 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). To model the deformations related with the ghost effects, the warping algorithm requires the knowlodge of water velocity, source and receiver depths.

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 the equation

$$y(t) = s(t) - \alpha s(t + \mu)\,, \qquad (1)$$

where s(t) is the desired signal, α is a scaling factor and μ is time-shift defined by the travel time difference between the ghost and primary reflections. In matrix notation, the equation becomes

$$\mathbf{y} = (\mathbf{I} - \mathbf{W})\mathbf{s}\,, \qquad (2)$$

where **W** is the warping operator responsible for the pulse deformation.

In real situation, 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:

$$\mathbf{y} = (\mathbf{I} - \mathbf{W}_s - \mathbf{W}_r + \mathbf{W}_{sr})\mathbf{s}\,, \qquad (3)$$

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. To construct the warping operators, it is necessary to compute the deformation parameters α and μ for each component. In practical applications, the free-surface reflection coefficient is approximated to -1 and the ratio between the primary and the ghost reflection coefficient is close to 1. Under this approximation, the scaling factor α is constant and equal to 1.

The present deghost method comprises two steps. In the first, travel times are computed, and then the warping system is inverted. Figure 2 shows a set of seismic traces which illustrates how the method works using as input a seismic trace with offset of 2000 meters. The first trace is the original trace used as input and the second is the free of ghost output. The next four traces are ghost components and the reconstituted signal, which are obtained by warping the output trace using the pre-computed travel time shifts. Compare this reconstituted signal with the original and observe that the main difference is noise, which is mostly constituted of low frequencies associated with the bubble effect.

Experiments

In this section, we present application examples of warping-deghosting using three different strategies. The first two examples are related to the use of the method in pre-stack datasets (shot gathers). In this case the ghost effect is not stationary, time shifts and amplitude scaling vary with time and offset. Ray-tracing can be used to compute both time-shifts and scaling factors, which are associated with angle-dependent reflection coefficients. The drawback of this approach is the presence of multi-arrivals events.

The first example is a synthetic shot recorder obtained by finite-differences using a complex velocity model in order to generate seismic reflections with triplications. Two simulations are perfomed, one with the air-water surface and another without it, in a such way that we have a seismogram with all ghost components (Figure 3a) and another without ghost reflections (Figure 3b).

In this case, the method of warping-deghosting was applied with approximations. The scaling factor was considered to be one, and the computation of time-shifts was performed using a 1D ray-tracing algorithm. Despite the use of these strong approximations the result is quite good even in the presence of triplications, see Figure 3c.

The second example corresponds to the application of the methodology described above in a shot record extracted from a 3D survey located in a pre-salt area of Santos Basinoffshore Brazil. This shot-record has 480 seismic traces with nominal source and receiver depths of 7 and 9 meters, respectively. This shot recorded was submitted to a very simple pre-processing sequence which consists of resample to 4 ms, swell noise attenuation, direct wave muting and bandpass filtering (Ormsby 2-4-70-80 Hz). Figure 4 shows a shot record without (left) and with (right) ghost effects removing. The white arrows are used to highlight a region where the deghosting step promoted a great impact in seismic resolution.

The last two examples correspond to the application of the zero-offset version of warping-deghosting algorithm in a time-migrated section. In the zero-offset case, all ghost reflections travel along the same direction, which implies that besides the direction and source-receiver depths, only the velocity of the water-layer is needed to compute time-shifts. Two features of implemented zero-offset algorithm were tested: the use in tau-p domain and the possibility of having an initial solution.

The main advantage of the tau-p approach is that each trace (constant p) has stationary time-shifts, which makes simpler the time-shift computation.

Figure 5 shows the migrated section and its corresponding amplitude spectra before and after deghosting. Observe the impact of deghosting in the low-frequency range.

Figure 6 exemplifies how the strategy which uses an initial guess works. On the left, we have the time-migrated section (input) before deghosting. On the middle, we have the first solution obtained with a maximum residue of 5%. This section is submitted to additional processing (filtering) and then used as initial guess in a second iteration of deghosting. The second iteration was performed with a maximum residue of 2 %, generating a refined solution. This strategy is much more stable than to direct minimize the residue to 0,1 %.

Conclusions

We present three different strategies of use of the warping-deghosting method, which is designed to remove all ghost components in one step. The method is applied to conventional marine streamer data without using any extra information than those are routinely used in conventional seismic processing.

The method is based on the premise that all ghost components can be obtained by deforming the desired component of the recorded data. This kind of deformation is carried out by a warping algorithm. The desired signal is an approximated solution obtained by a conjugate gradient solver.

Besides the free-of-ghost component, all the other ones can be obtained to reconstruct the data and check the solution by means of the observed residue.

The method is applied in both synthetic and real datasets. The results show an outstanding gain of quality of migrated section with an enhancement in the bandwidth of amplitude spectra. These improvements, not only produces an image with better resolution, 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. Basically, the construction of warping operators depends only on small time-shifts measurements, which can be obtained in several ways, leading to a very flexible deghosting tool.

Acknowledgments

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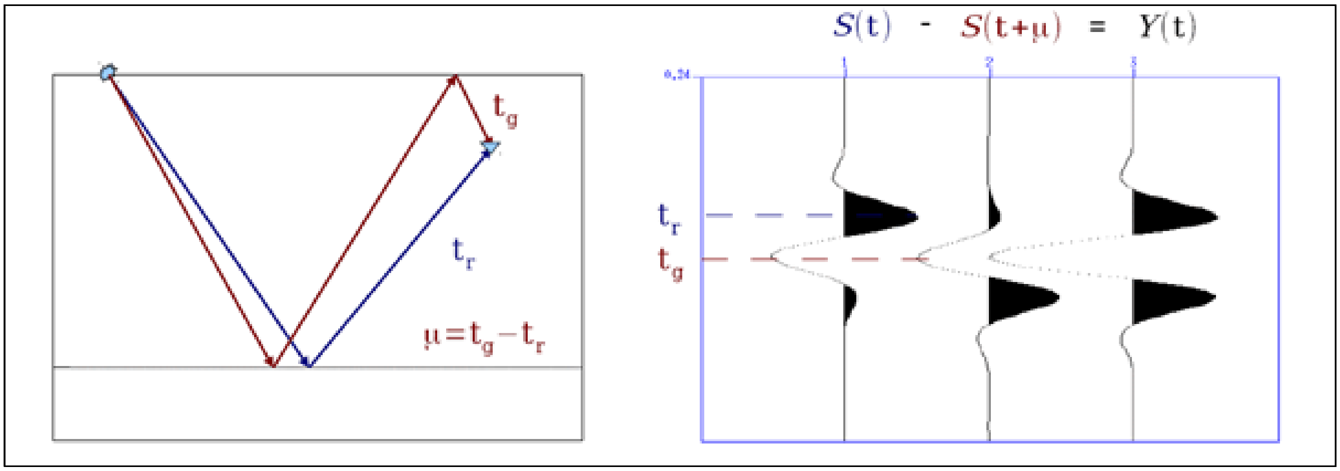


Figure 1. Simulation of receiver ghost only illustration, μ is the travel time difference between ghost time (t_g) and primary reflection (t_r).

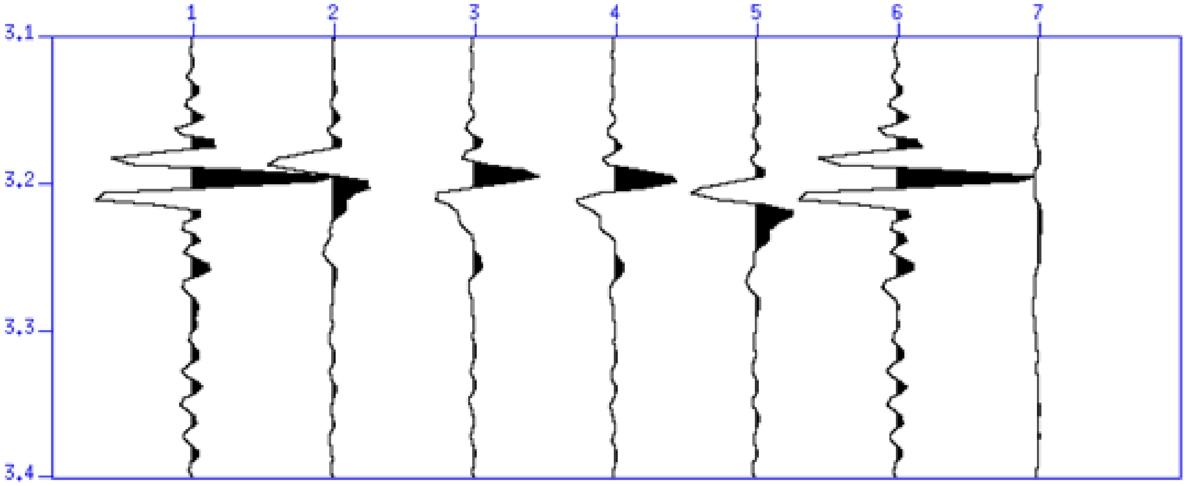
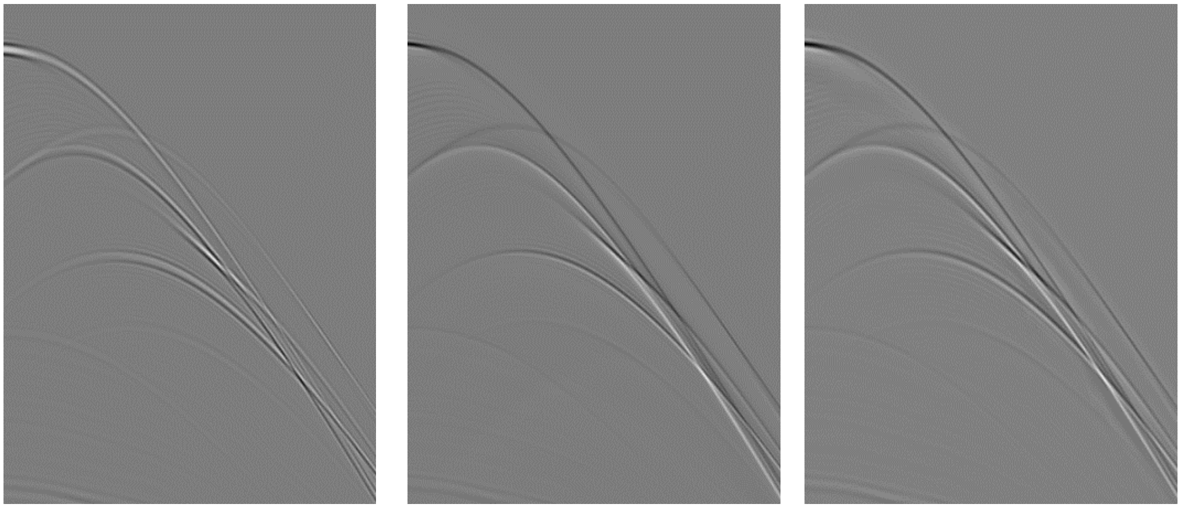


Figure 2. Ghost attenuation and decomposition applied on a raw real data with an offset of 2000 m : 1-Input data, 2-output solution of the ghost-warping system, 3, 4 and 5 ghost components respectively from source, receiver and source-receiver component, 6) reconstituted signal (sum of all components) , and 7) difference between the recorded data and the reconstituted data (residue).



a) b) c)

Figure 3: Synthetic seismograms: a) shot gather modeled with source and receiver ghost components, b) shot-gather modeled without ghosts, and c) shot-gather with ghosts after warping deghosting.

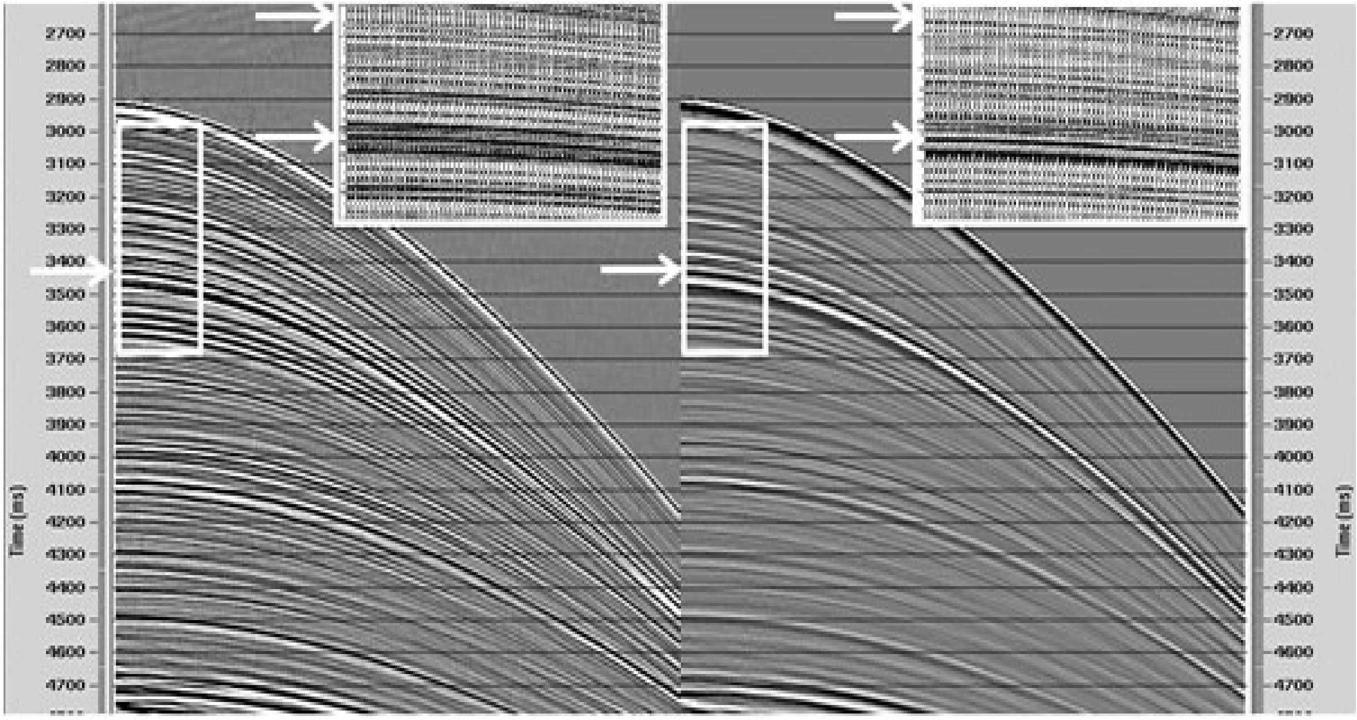


Figure 4. Shot gathers after deghosting, on the right, and before on the left. Observe how the reflectors, pointed by the arrows in zoomed box, look different.

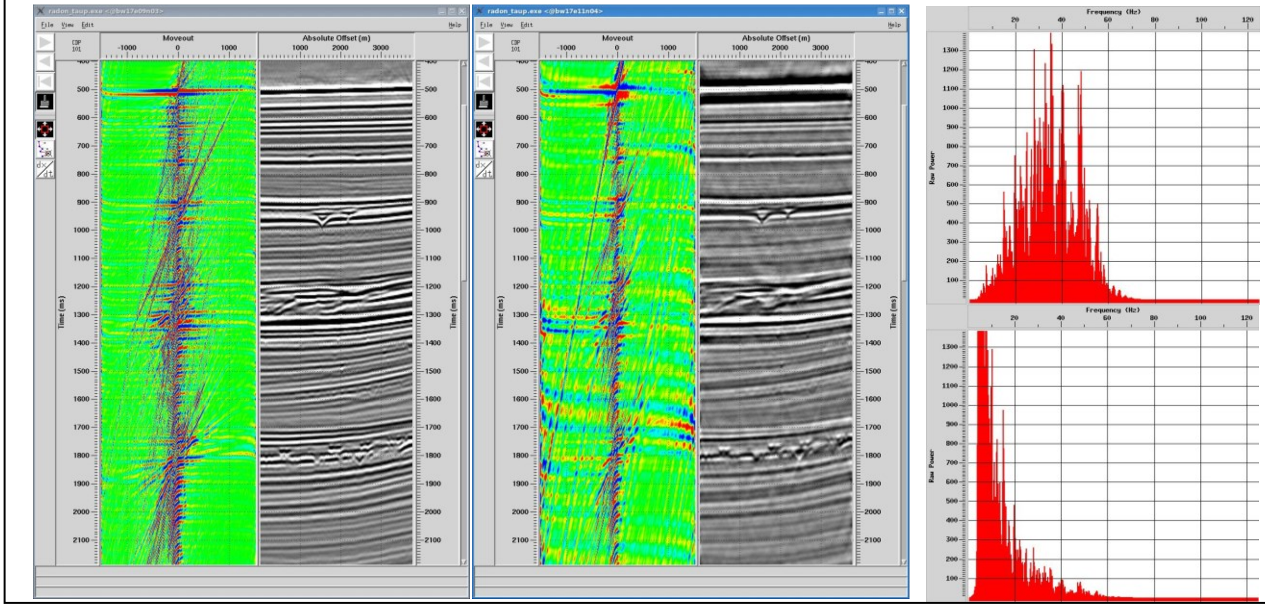


Figure 5. Zero offset Deghosthing by Warping implementation, applied in Tau-P domain. Left input stacked section (in tau-p and x-t domains). Right the same stacked data after deghosting. In the very right the amplitude spectra before and after deghosting.

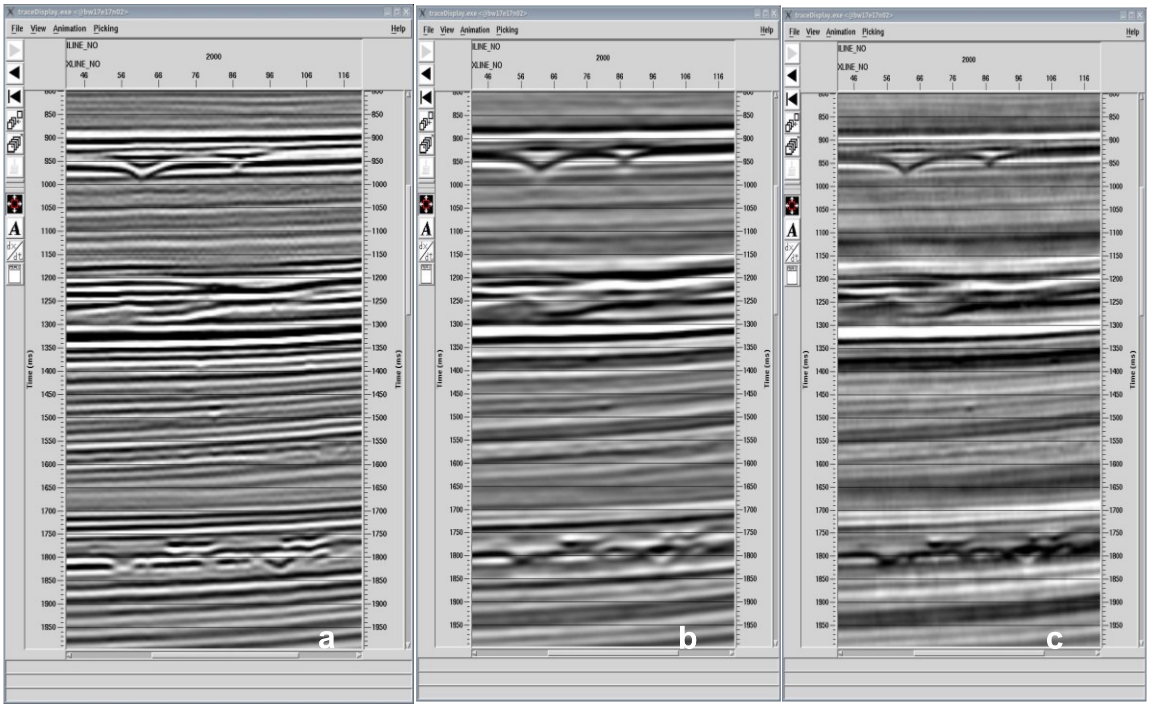


Figure 6. Zero Offset Deghosting by Warping using successive approachs. (a) input, (b) first deghosting with 5% of residue and (c) deghosting with 2% residue applied in (b), total residue of 0,1%.