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Fine-Tuning Multiple Suppression via Warping Filter

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ABSTRACT

We present and discuss some improved results with a recently developed method for multiple suppression in the near-offset domain by using warping filters. The main steps of the application of the method are (a) simulation of multiples by means of Kirchhoff-type summations applied to a common near-offset section; (b) application of an adaptive filter to adjust simulated multiples, and (c) subtraction from the original data. Our approach consists in deforming simulated multiples in order to match the geometry of observed multiples. A mesh warping specification was chosen due to its simplicity, efficiency, and robustness. The warping technique has been successfully applied to correct strong deformations present on simulated multiples in shallow-water data.

INTRODUCTION

Routine interpretation of processed seismic data is mainly focussed on understanding primary reflections. Multiples, however, are also present in all seismic reflection data acquired in both land and marine environments. If not properly attenuated or removed, multiples can interfere with primary reflections, leading to difficulties in velocity analysis or some attribute estimation.

In many land data cases, multiple attenuation can be adequately achieved by deconvolution and CMP stacking. Due to the presence of the strong reflections on the water-air contact (free surface), marine data most often require specific processing steps. In general, methods of multiple suppression can be divided into two categories: filtering and wavefield prediction and subtraction. Methods of the first group are based on the exploitation of some difference between multiple and primary reflections. The popular Radon and *f-k* transform algorithms, generally applied in CMP domain, belong to this category. Algorithms of the second group predict and subtract a given multiple type based on a wave propagation approach. The near-offset multiple suppression method (Filpo and Tygel, 1999) here used is included in the second group.

The use of adaptive techniques to match discrepancies between predicted and observed multiples is a common procedure applied before subtraction. In order to preserve primary events, adaptive filters should not be very effective. Filters with small number of samples can adjust multiples without incorporating primary information. That is possible when simulated and observed multiples are very close. In this work, we show how to apply a warping technique to previously adjust the simulated multiples.

MULTIPLE SIMULATION

Theoretically, the simulation method is designed to apply a transformation of a given 2D zero-offset input section, containing all primaries and multiples, resulting in an *output* section which solely consists of multiples to be suppressed. In this case, these are first-order sea floor and peg-leg multiples. In a Kirchhoff-type stacking algorithm, each sample of the output section is the result of a sum of samples collected along an uniquely specified curve in the input section. This curve is generically called the *stacking line*. In most cases, input samples along the stacking line are multiplied by certain weights, also determined by the sample in the output section, where the resulting sum is to be placed. The terminology *weight function* is employed here to refer to the choice of multipliers that are used in the summation process, which in turn is called *weighted Kirchhoff stack*.

The method is expected to work well on any seismic section that is a reasonable approximation of a zero-offset section. For small dips, near common offset sections after NMO correction can be good approximations for input zero-offset sections. For steeper dips and/or greater offsets, further DMO corrections are necessary. CMP-stacked sections can be also used as input sections for the proposed method. Better results are obtained in deep water situation because the traveltimes for sea floor and peg-leg multiples can be well approximated under the assumption of the constant-velocity medium for water, see Filpo and Tygel (1999).

WARPING

Although quite precise (Filpo and Tygel, 1999), the method described above may result in slight differences in both time and spatial positioning of predicted multiples when some premises are not satisfied. The most usual cause for mispositioning of simulated multiples is out-of-plane reflections. In addition, improper transformation to zero-offset can produce false simulated multiples. These differences become important for multiple prediction in shallow-water. In this case, the NMO correction applied on sea-bottom primary reflections strongly distorts the shape of the seismic pulse in the zero-offset input section. The resulting simulated multiples present on the output sections become abnormally deformed by stretching, causing the multiple suppression method to fail. Moreover, the degree of mispositioning varies throughout the data. Although static time-shifts may provide a partial solution, they do not allow for spatial and time-variant corrections necessary for a more effective multiple attenuation, where even sub-sampling differences may result in observed/predicted multiples mismatch.

One way to tackle the problem is by means of a geometric deformation of the predicted multiple field using warping filters. Warping is a continuous deformation of graphical objects (Gomes et al., 1998) and comprises a broad family of transformations. We are particularly interested in the subgroup defined by projective transformations of images to an arbitrary line (2D).

Warping specification

There is a close relationship between warping and change of coordinates. Therefore, a logical choice is to use a coordinate system to specify the warping. This is the most important step in the definition of a warping filter. There are several ways to specify the coordinate transformation (Gomes et al., 1998). We have chosen the mesh warping specification for our application due to its simplicity, efficiency, and degree of control. In this specification, the coordinate system is represented by some mesh whose nodes define control points. By changing the mesh arrangement one changes the coordinate curves, defining a change of coordinates that performs the desired warping.

Two-pass spline mesh warping

This technique was first described in (Wolberg, 1990). The coordinate system is represented by using two regular spline meshes (Figure 1A). The source mesh defines the undeformed coordinate system, while the target mesh describes the final deformed state of that system. Both meshes are restricted to have rectilinear and coincident borders. The use of meshes of spline curves connotes a uniformly smooth transformation. The computation of the warping is done by separating the transformation into a horizontal and a vertical pass. The separation makes this technique very efficient, since each pass performs essentially a much simpler set of 1D transformations instead of the complete mapping. Decomposing the whole mapping into multiple 1D problems is also especially attractive for handling sampling and reconstruction problems since filtering can be done in a very simple and efficient way.

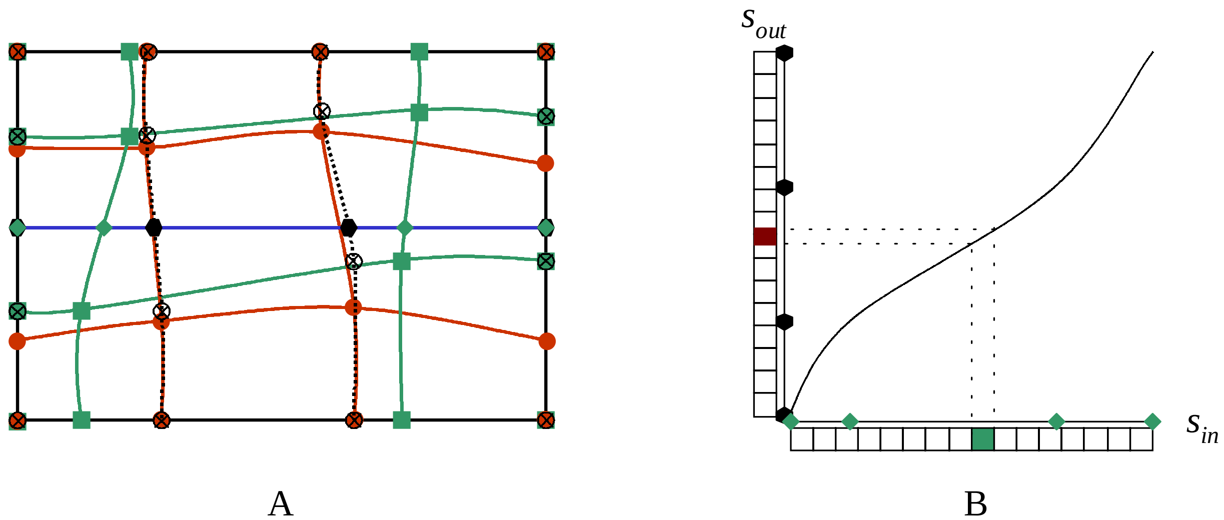

Figure 1: Mesh warping construction (modified from Gomes et. al., 1998). A) Relationship among source (green), target (red), and intermediate (dotted black) meshes. A scanline (blue line) and the intersections with source (diamonds) and intermediate meshes (hexagons) are shown. These points are used to build B) the scanline mapping function.

Both passes are analogous and can be performed in any order. The horizontal pass follows this algorithm:

a) Construct vertical splines with horizontal displacements only;
b) Intersect each scanline with vertical splines;
c) Construct the scanline mapping function.

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In the first phase, intermediate control points representing the horizontal displacements from the source mesh into the target mesh are defined. These intermediate control points are used to construct a vertical spline mesh. Figure 1A shows the superposition of the source, target, and intermediate meshes. Each horizontal scanline is then intersected with the vertical splines in the source and intermediate states. Finally, these intersections are used to construct the scanline mapping function (Figure 1B) by placing intersections with the source splines versus intermediate splines. This function relates all pixels of the scanline in the original coordinate system to pixels on the deformed state. This process is repeated for each scanline to obtain a horizontally deformed image, which is then passed to the vertical pass.

MULTIPLE SIMULATED ADJUSTMENTS

Our approach consists in picking multiples in both predicted and observed sections. Picking both sidelobes of each event greatly improves the final matching in terms of both frequency and amplitude. Each set of picking times is interpolated and dense smooth curves are constructed. These curves are correlated laterally in order to correct for residuals left by the original method. The set of curves is then framed (padded and/or clipped, if necessary), allowing enough space below the deepest curve to avoid any border effect. Finally, both source and target meshes are built and input to the warping algorithm.

RESULTS

The method has been applied to a shallow-water marine 2D data. Figure 2 shows the improvement achieved in matching simulated multiples with observed data for a single trace. Trace A belongs to the input zero-offset section, where primary and multiple reflections are observed, while trace B belongs to the simulated multiple section. Notice the variable time shift and low frequency character introduced by the NMO correction. Trace C is the result of applying the warping filter over the trace B. Notice the good traveltime and pulse shape adjustments.

The application the warping filter generates a new section of simulated multiples, where not only the traveltimes are better predicted but also frequency and phase of the seismic signal are closer to the observed multiples. This new section is more suitable to be adjusted by adaptive filters than the first one.

Figure 3 shows the improvement in stacked sections. Figure 3A is the stacked section without any multiple suppression. Figure 3B is the corresponding section after the suppression of the multiples adjusted only by adaptive filter. Figure 3B is the result using the warped multiples as input to adaptive filter. Notice very effective the multiple suppression at 300 ms and 550 ms.

The improvement in multiple suppression using the warped version (Figure 3C) over the original method (Figure 3B) is evident.

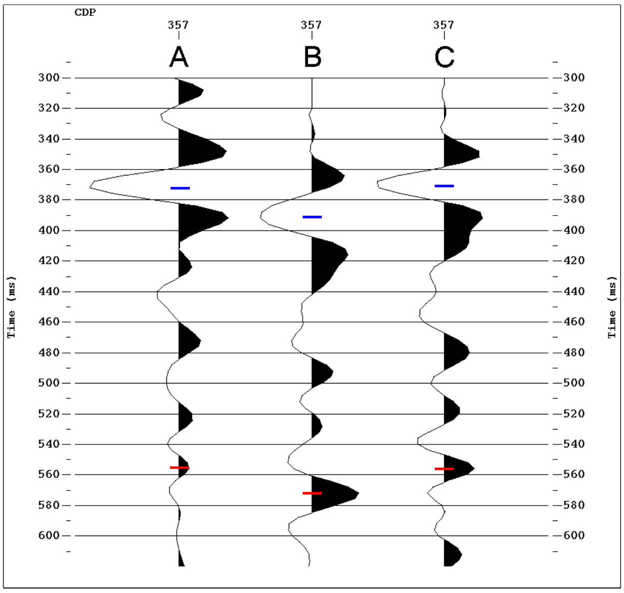

Figure 2: A) Observed data, B) simulated multiples, and C) warped multiples.

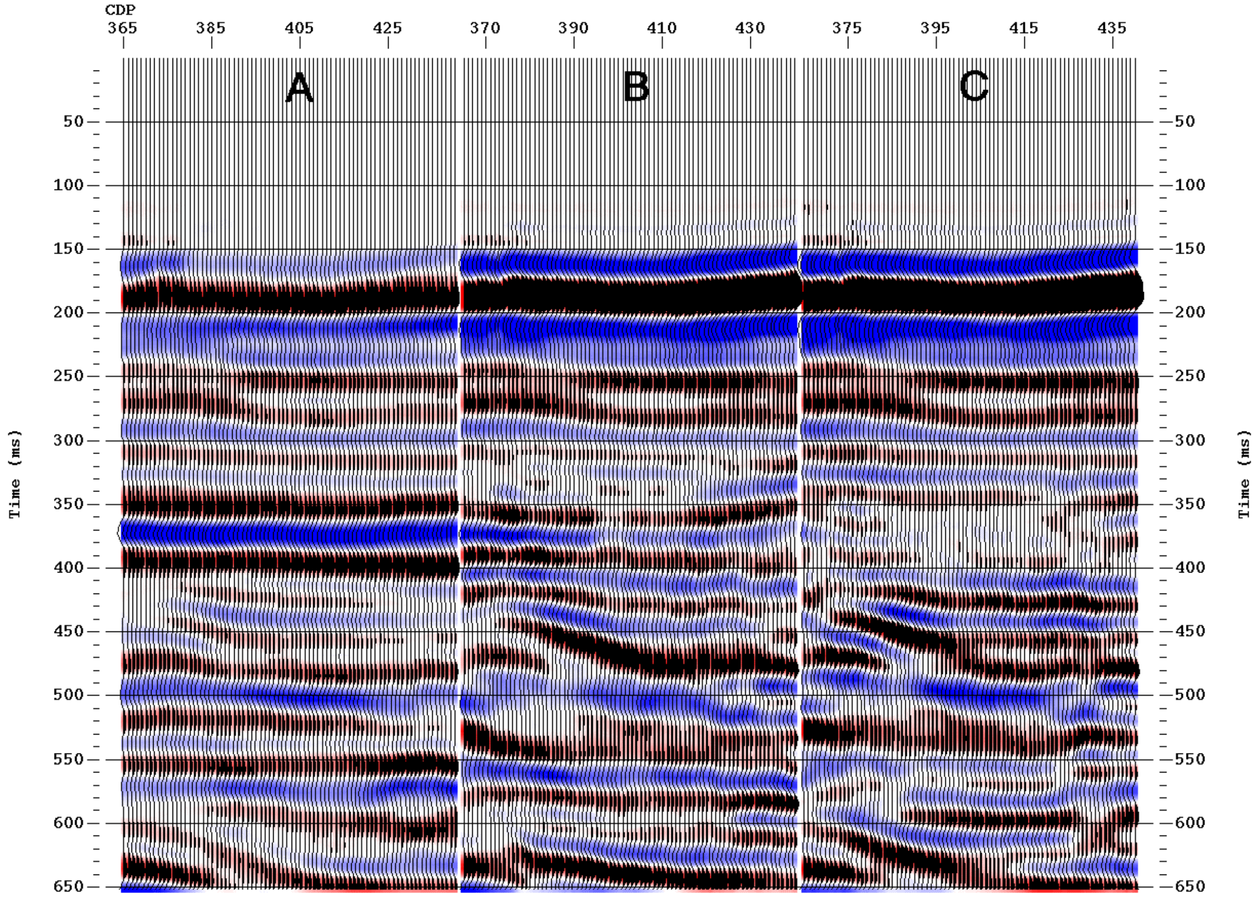

Figure 3: A) Observed data; B) resulted obtained with the original method, and C) result obtained with warping predicted multiples.

CONCLUSIONS

We have presented a method to improve an already efficient method of multiple suppression and tested it in a shallow-water seismic data. After the warping filter, the predicted multiples match very closely the observed data in terms of geometry, amplitude and frequency. The improvements are of great importance for the case of shallow-water multiples.

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