Cross-correlation based time warping of one-dimensional seismic signals

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ABSTRACT

The computation of a dynamic displacement field between pairs of seismic traces has numerous geophysical applications including the estimation of displacement vectors in time lapse seismic, P- to S-wave image registration and residual moveout correction. In this paper, I present a cross-correlation based methodology for the estimation of small time displacements between signals followed by stretching to match the signals. The utility of the algorithm was demonstrated through a synthetic time lapse example illustrating production effects and the associated time shifts between baseline and monitor surveys. The differencing of the baseline and monitor traces prior to warping results in apparent amplitude changes below the reservoir interval. Upon application of the warping algorithm, the undesirable amplitude changes below the reservoir interval are reduced.

INTRODUCTION

The need to compute a dynamic displacement field and the subsequent warping or matching between pairs of signals is often required in the field of signal processing. The use of these techniques spans various disciplines ranging from speech recognition (Sakoe and Chiba, 1978) to numerous geophysical applications. For example, Hale (2009) estimated apparent displacement vectors from time lapse seismic (4D) images and Herrera and van der Baan (2012) used dynamic time warping for seismic to well-ties. Other geophysical applications include P- to S-wave image registration and residual moveout correction. Various methodologies have been proposed in the literature to achieve the goal of matching two signals with time variant shifts. These include cross-correlation based techniques (e.g., Hale, 2009) as well as optimization techniques where a cost function is minimized to obtain a solution (e.g., Herrera and van der Baan, 2012; Hale, 2013). The applicability of these two different approaches are then related to the rate at which the shifts vary, where rapidly varying shifts are better handled by optimization techniques and smaller shifts can be handled by cross-correlation (Hale, 2013).

In this paper, I present a cross-correlation based methodology for estimating small time shifts in one-dimensional seismic signals related to (1) 4D effects due to changes in reservoir conditions over time or (2) residual moveout in common midpoint (CMP) gathers. The motivation for (1) is that warping of 4D seismic signals allows for a direct comparison of changes in reflection amplitudes due to production effects without the accompanying time shifts below the reservoir interval, and (2) is that warping of offset traces in a CMP gather could improve AVO analysis by correcting residual moveout. In the following, I discuss the steps involved in estimating the dynamic displacement field followed by stretching to match the signals. Subsequently, I demonstrate the applicability of the algorithm with a synthetic 4D example.

METHODOLOGY

The algorithm to warp the seismic signals presented here involves two main steps. First, a time displacement field is computed between two signals, a baseline and monitor, where the baseline serves as a reference. Second, the monitor signal is stretched according to the computed time displacement field. In the following, a description of the procedure involved for each step is given.

1. Computation of time displacement field:

    a. AGC – A gain is applied to both the baseline and monitor traces to equalize the amplitudes.

    b. Interpolate – Since the time shifts are defined to be small and can be less than the data sample rate, an interpolation is performed to oversample the traces.

    c. Compute the envelope function – The computation of the time displacement field is performed on the envelope function or the magnitude of the original signal and its Hilbert transform. This is implemented to account for polarity reversals such as those encountered in class 2 AVO.

    d. Windowed cross-correlation – A sliding window is used for the computation of local time shifts. The lag associated with the maximum correlation coefficient within each window represents the localized time displacement between the baseline and monitor traces.

2. Stretching

    a. Mapping to new time coordinates – The original time vector for the monitor trace is modified according to the computed time displacement field. The corresponding samples for the monitor signal are mapped to the new time coordinates.

    b. Interpolate – The stretched monitor trace is interpolated back to the original sample rate.

EXAMPLE

To demonstrate the applicability of the proposed methodology, I present a synthetic example to illustrate the effect of differencing of a baseline and monitor seismic trace, where the 4D effects are the result of changes in reservoir conditions over time.

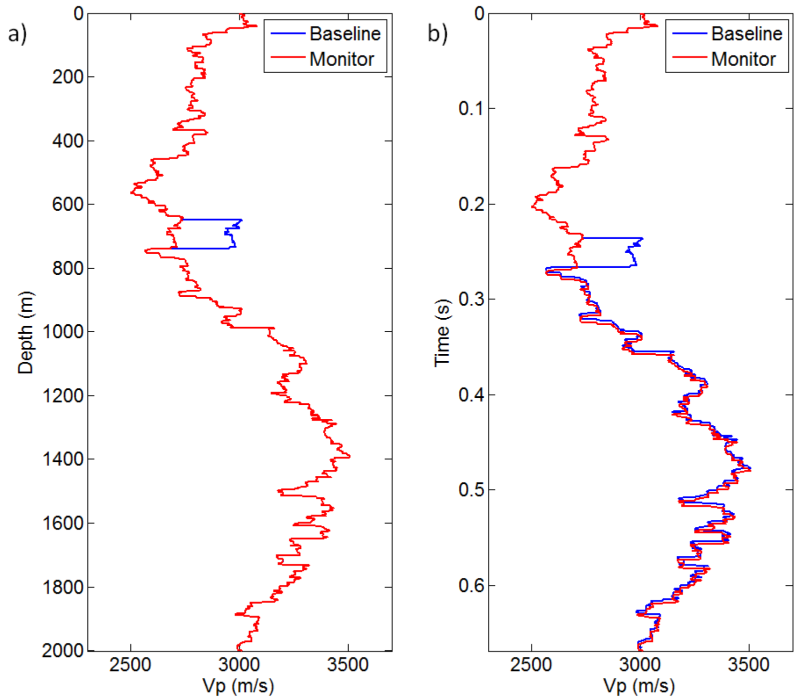

FIG. 1. Baseline and monitor P-wave velocity logs in a) depth and in b) time. In the time domain, a shift due to an increased traveltime is observed in the monitor log.

Figure 1 shows the baseline and monitor P-wave velocity logs in depth and in time, where the time-depth relationship was derived by integrating the slowness function. The monitor log exhibits a decrease in P-wave velocity over the reservoir zone that represents production effects. In the depth domain, only a change in P-wave velocity over the reservoir zone is observed. However, in the time domain, a change in P-wave velocity as well as a time shift due to an increased traveltime is observed. Figure 2 shows the corresponding seismograms for the baseline and monitor traces and their difference. Apparent changes in reflection amplitudes are observed below the reservoir interval that result from time shifts associated with the monitor trace. These effects are undesirable as the changes are not isolated to the reservoir interval, making direct comparisons of the time lapse signals more difficult.

To address the differencing issue associated with the time shifts, I apply the proposed time warping methodology. Figure 3 demonstrates the process where a cross-correlation function is computed for a windowed section of the baseline and monitor traces. The lag associated with the maximum correlation coefficient represents the time shift for a localized section of the trace. A sliding window across the entire trace generates the time displacement field as shown in Figure 4.

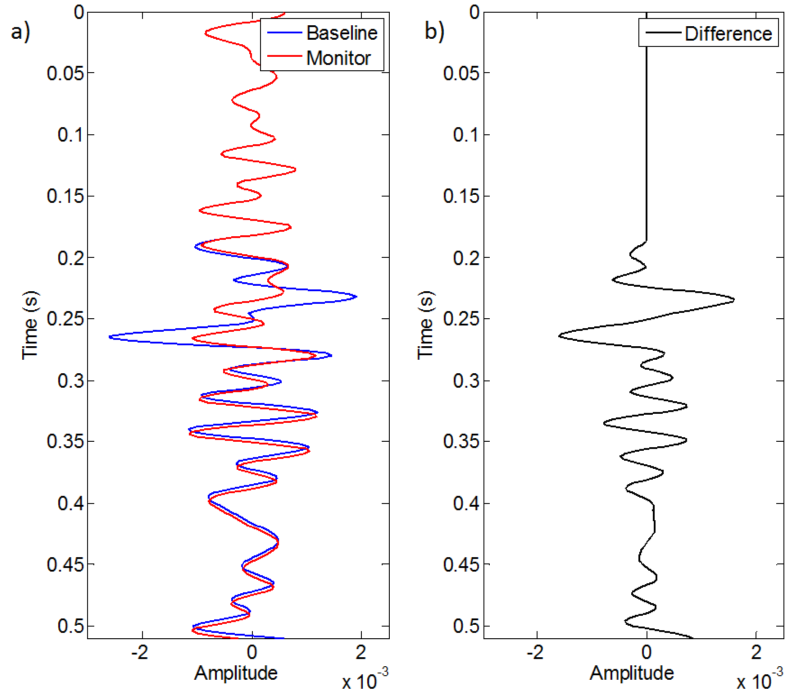

FIG. 2. a) Baseline and monitor seismograms and their b) difference. Note the apparent changes in reflection amplitudes below the reservoir interval that result from time shifts associated with the monitor.

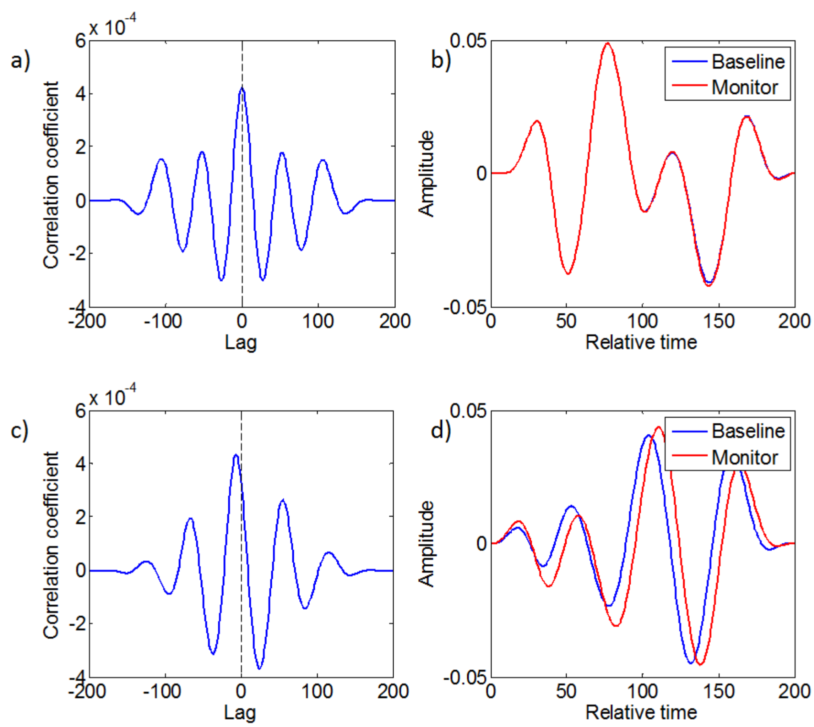

FIG. 3. The a) cross-correlation function computed from a section of the b) baseline and monitor traces with no shift and the c) cross-correlation function computed from a section of the d) baseline and monitor traces with a finite shift.

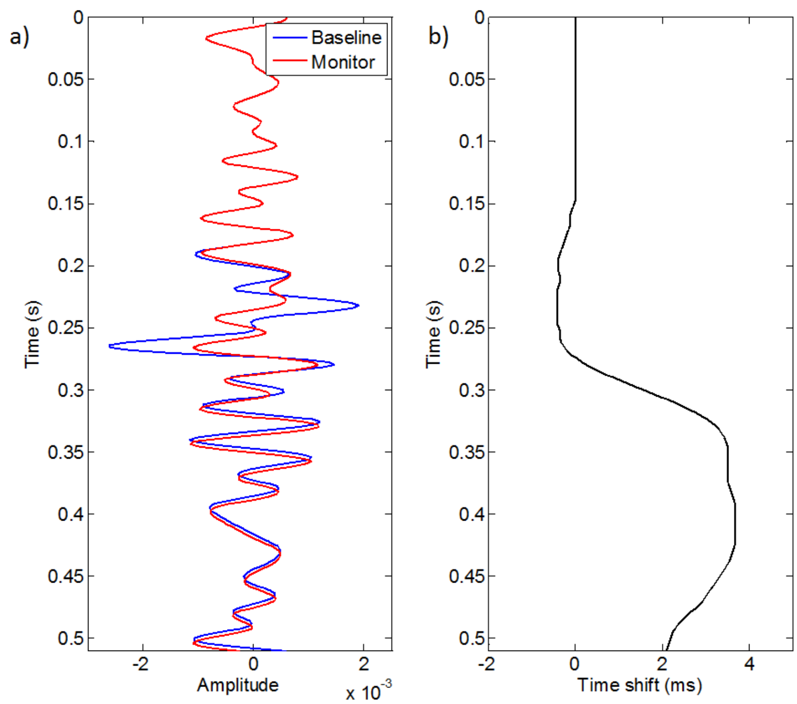

FIG. 4. a) Baseline and monitor seismograms and the associated b) time displacement field.

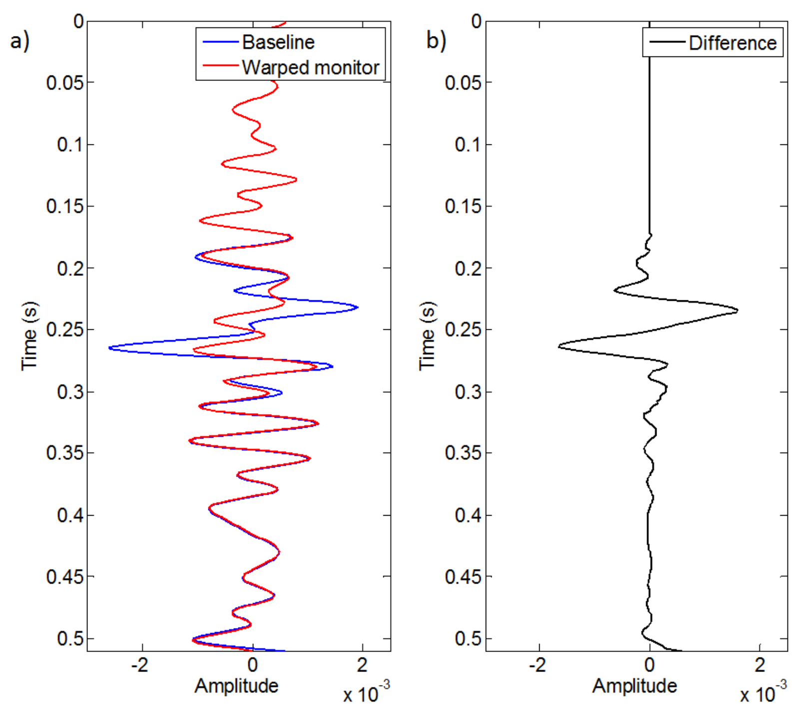

FIG. 5. a) Baseline and warped monitor seismograms and their b) difference. Note the reduction in amplitude changes below the reservoir interval.

Figure 5 shows the baseline and warped monitor trace and the associated difference. Note that the time shifts are reduced between the seismograms and the amplitude differences are now localized to the reservoir interval.

CONCLUSIONS

A cross-correlation based time warping technique was presented to address issues associated with small dynamic time shifts that arise from production effects in 4D seismic or residual moveout in CMP gathers. The algorithm was presented and demonstrated through a synthetic 4D example. Time shifts in the monitor trace resulted in amplitude issues below the reservoir interval when differenced from the baseline. The warping algorithm reduced these effects making a direct comparison of the time lapse signals more tractable.

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