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

- Warping of time series signals has applications ranging from speech recognition (Sakoe and Chiba, 1978) to geophysical data analysis
- Warping techniques include:
  - Cross-correlation based techniques – for smaller shifts
  - Optimization techniques – for rapidly varying shifts
- Geophysical applications include:
  - Apparent displacement vectors from time lapse (4D) seismic images (Hale, 2009)
  - Seismic to well-ties (Herrera and van der Baan, 2012)
  - P- to S-wave image registration
  - Residual moveout correction
- Here, a cross-correlation based methodology is presented for estimating small, one-dimensional time shifts related to:
  - 4D seismic signals allowing for a direct comparison of changes in reflection amplitudes due to production effects without the accompanying time shifts below the reservoir interval
  - Residual moveout correction in CMP gathers for improved AVO analysis

METHODOLOGY

- 1. Computation of time displacement field
  - AGC – A gain is applied to both the baseline and monitor traces to equalize the amplitudes
  - 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
  - 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
  - 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
  - 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
  - Interpolate – The stretched monitor trace is interpolated back to the original sample rate

EXAMPLE

- Synthetic 4D example illustrating the differencing of a baseline and monitor trace

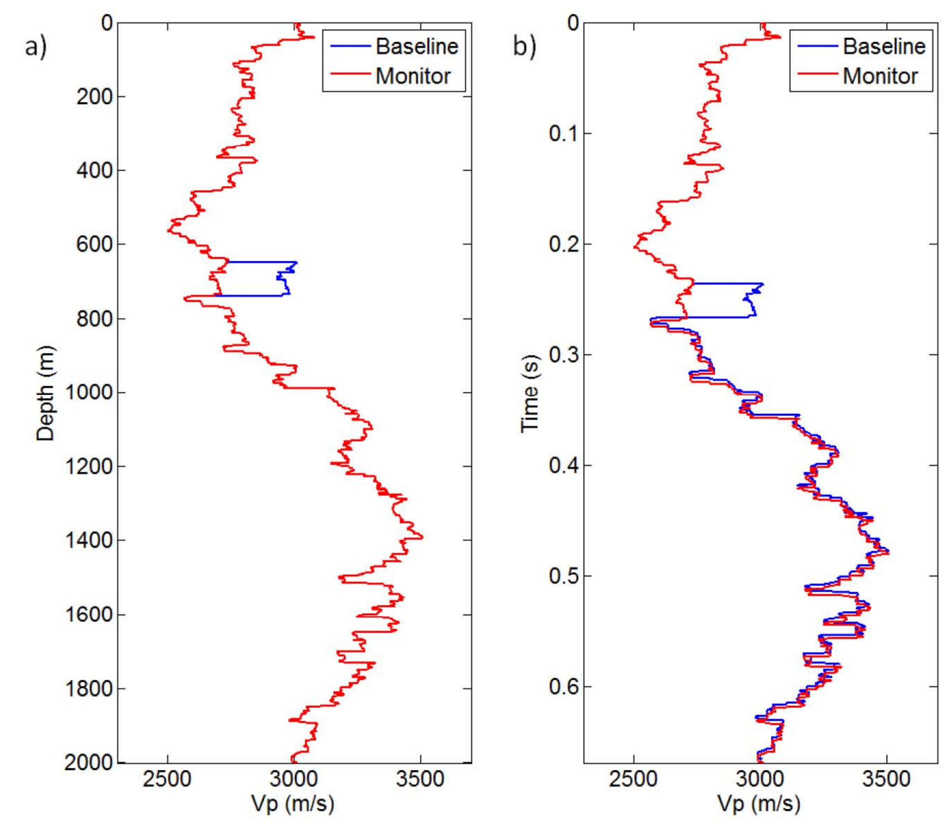

FIG. 1. Baseline and monitor P-wave velocity logs in a) depth and in b) time. In the time domain, a shift due to an increased traveltime is observed in the monitor log.

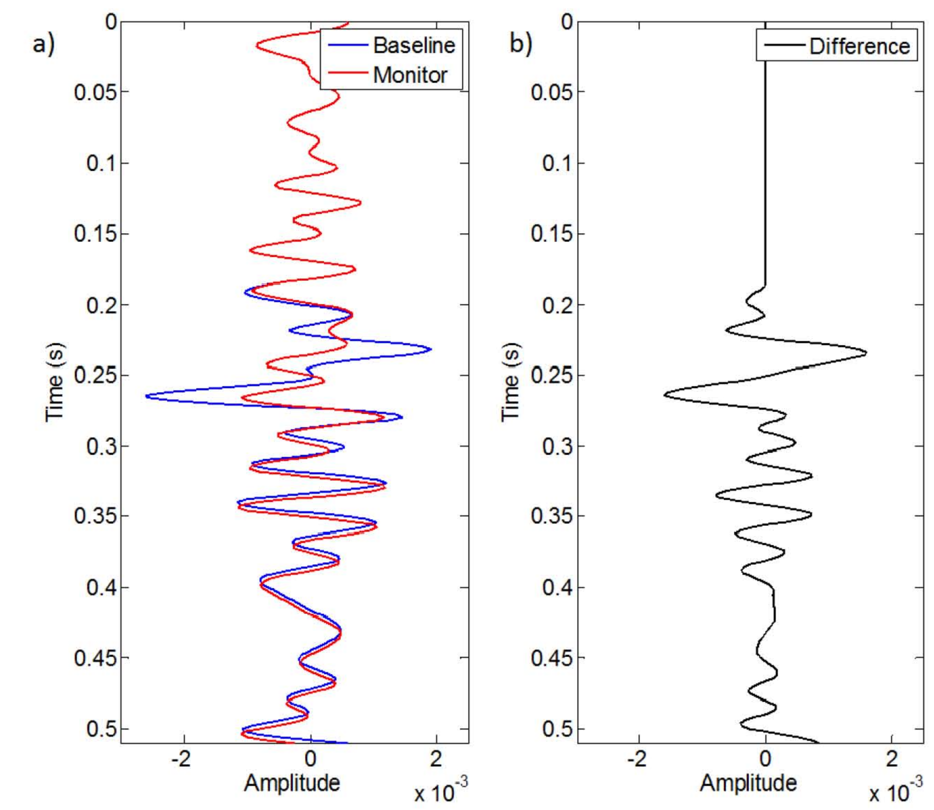

FIG. 2. a) Baseline and monitor seismograms and their b) difference. Note the apparent changes in reflection amplitudes below the reservoir interval that result from time shifts associated with the monitor.

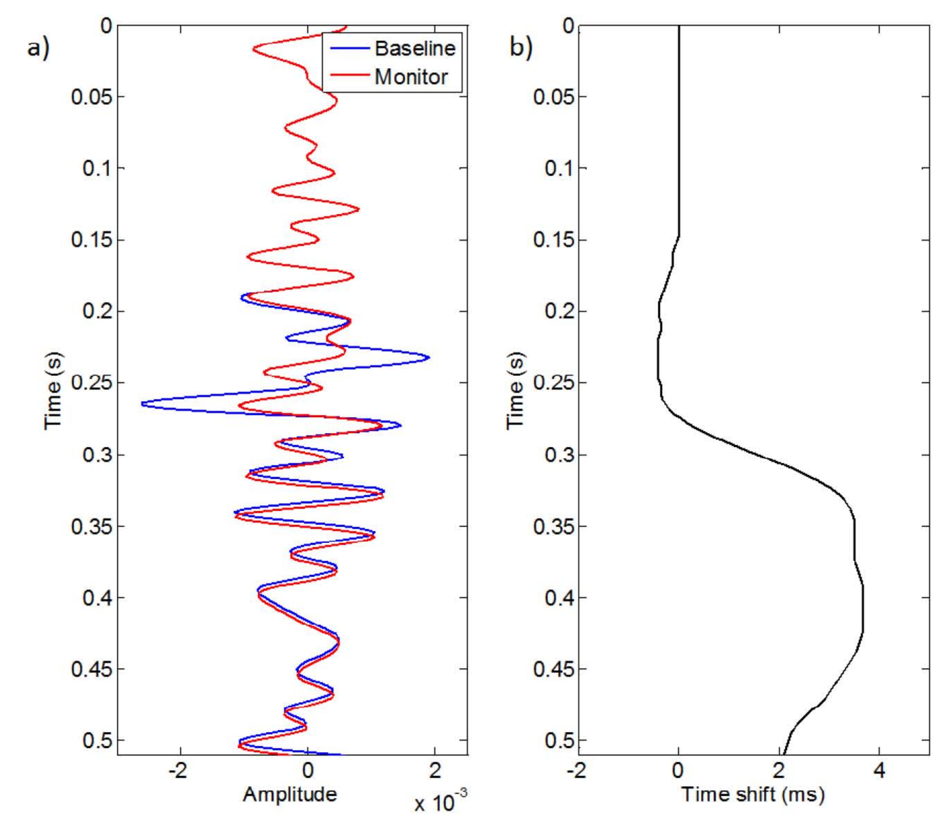

FIG. 3. a) Baseline and monitor seismograms and the associated b) time displacement field.

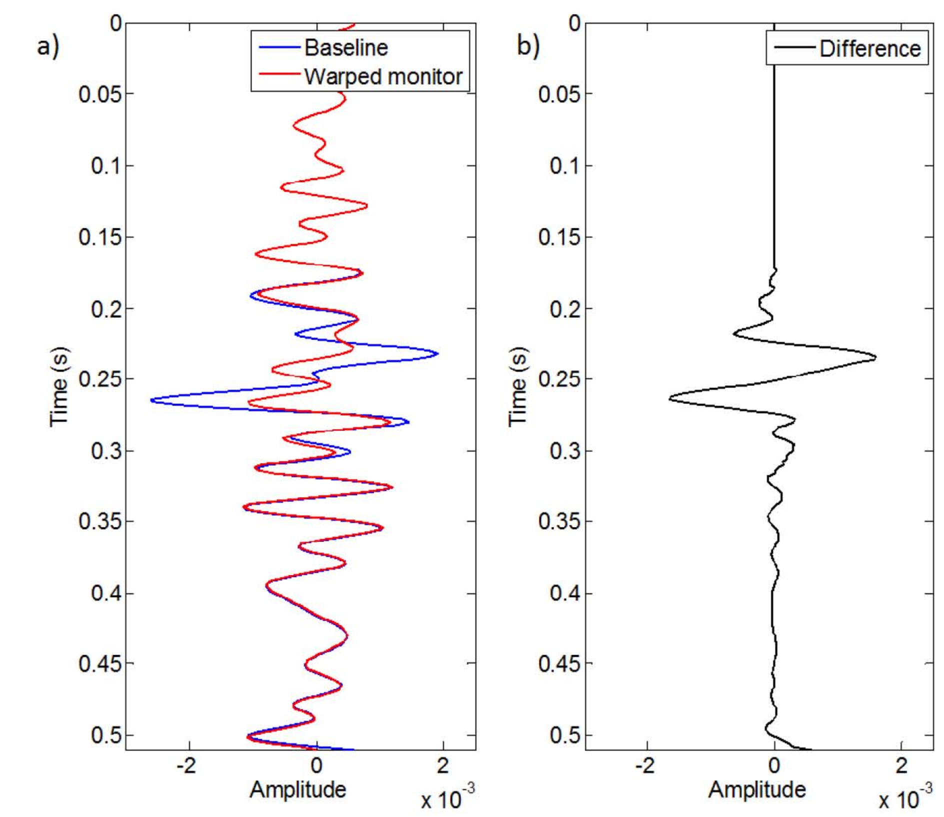

FIG. 4. a) Baseline and warped monitor seismograms and their b) difference. Note the reduction in amplitude changes below the reservoir interval.

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.