Journal of Applied Geophysics 135 (2016) 183–190

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Simultaneous deghosting and wavelet estimation via blind deconvolution

Hojjat Haghshenas Lari*, Ali Gholami

Institute of Geophysics, University of Tehren, Tehran, Iran

ARTICLE INFO

Article history:
Received 20 September 2015
Received in revised form 4 August 2016
Accepted 12 October 2016
Available online 15 October 2016

Keywords:
Blind deconvolution
Deghosting
Marine seismic data
Source/receiver ghosts
Wavelet estimation

ABSTRACT

Seismic deconvolution and deghosting are common methods for increasing the temporal resolution of marine seismic data. In this paper, we employ the advantages of multichannel blind deconvolution technique to obtain a deghosting algorithm for source and receiver side ghost elimination. The advantage of the proposed algorithm is two fold: first, it uses the correlation between the information contained in neighboring traces to stabilize the deghosting process while deconvolving the data in a blind fashion. Second, an estimation of the source wavelet is simultaneously provided by the inversion process. A fast algorithm is provided to solve the inverse problem by using the split Bregman iteration. Numerical results from simulated and field seismic data confirm the effectiveness of the proposed algorithm for automatic deghosting and deconvolution of marine data while being able to recover complex mixed-phase source wavelets.

1. Introduction

In marine seismology, ghosts are defined as the reflections of source energy from air-water discontinuity that trail behind the original source impulse by a delay. Generally, if the energy starts its propagation upward from the source and reflects back from the sea surface it is called source ghost; otherwise, if the reflection of the surface ends its propagation in the receiver location it is called receiver ghost. Theoretically, if the air-water discontinuity is a flat surface and the ghosts do not change during propagation from the source to the surface or from the receiver to the surface, then the ghosts are simply a polarity-reversed copy of the source generated wavelet (Day et al., 2013).

Ghosts reduce the resolution of marine seismic data by introducing notches into its frequency. Depending upon the distance of source/receiver from the surface, ghosts add one or more types of notches to the spectrum of recorded data and thus decrease the temporal resolution of the data. Therefore, processing tools are required in order to compensate for the blurring effects of the ghosts and increase the resolution of the data (Mayhan and Weglein, 2013).

The action of ghost elimination from recorded seismic data is called deghosting, which has been a long-standing problem in the processing of marine data. Deghosting process can take the advantages of new data acquisition methods such as hydrophone-geophone streamers, dual-streamer towing, or slanted-streamer towing (Day et al., 2013; Özdemir et al., 2008; Soubaras and Lafet, 2013; Hill et al., 2006; Moldoveanu et al., 2007). However, recent interests in obtaining broadband seismic data leads research into processing-based deghosting techniques applicable to conventional streamer data (Amundsen et al., 2013). Such methods have been developed to meet the need of seismic exploration for obtaining a high resolution marine seismic data. Many different techniques with different approaches have been developed. Ghosh (2000) and Amundsen et al. (2013) used deconvolution to deghost seismic data, Mayhan and Weglein (2013), Amundsen et al. (2013) and Wang et al. (2012) take the advantages of Green's function to remove ghosts, and Robertsson and Amundsen (2014) and Amundsen and Robertsson (2014) used a finite difference method for this purpose. The domain in which deghosting is applied can be different as well. Some take the advantages of frequency domain to compensate for the lost frequencies (Amundsen et al., 2013; Robertsson and Kragh, 2002; Amundsen, 1993), while there are some other methods which are applied in the time-space (Robertsson and Amundsen, 2014) or τ-p domains (Ferber et al., 2013). Frequency domain methods may suffer from the presence of poles at some fundamental frequencies, called notch frequencies, in their deghosting operators (Amundsen et al., 2013; Robertsson and Amundsen, 2014), while the methods performed in the time-space domain may be more stable in all frequencies.

In this paper, we introduce a deconvolution-based deghosting algorithm by using the blind-deconvolution approach introduced

---

* Corresponding author.
E-mail addresses: hojjat_lari@ut.ac.ir (H. Haghshenas Lari), agholami@ut.ac.ir (A. Gholami).

http://dx.doi.org/10.1016/j.jappgeo.2016.10.009

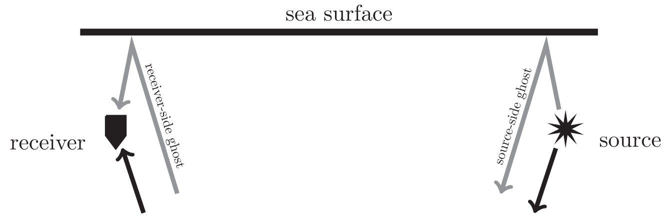

Fig. 1. Graphical representation of source-receiver configuration with source-side and receiver-side ghosts.

Table 1
Blind deconvolution algorithm for deghosting.

```
Initialization: estimate a rough source wavelet, $w_s$,;
repeat:
    fix $w_s$, solve ($P_X$) for $X$;
    fix $X$, solve ($P_{w_s}$) for $w_s$;
until {the change in $w_s$ or $X$ is negligible}
Output: convolve $X$ with $w_s$ (or any desired wavelet)
        to achieve the deghosted version of data;
```

in Gholami and Sacchi (2013). We assume that the sea surface is nearly flat, the acoustic impedance of the water does not change, and the ghost wavelet is not modified during its travel from the source (surface) to the surface (receiver). We also suppose that the travel-time of the ghost energy from source/receiver to water surface is known. One of the advantages of the proposed method is that it is applied in the time-space domain and hence it may have less difficulties with the notch-frequencies. Furthermore, it is performed in a multichannel form and hence uses the correlation between the information contained in neighboring traces to stabilize the deghosting process. The other advantage is its ability to estimate the source generated wavelet while deghosting. We examined our method on both synthetic and real marine seismic data, and observed a convincing performance of the method in both deghosting of seismic data and recovery of complicated mixed-phase wavelets.

2. Theory

A modified wavelet that follows the original source impulse by a slight time delay is defined as the ghost wavelet (see Fig. 1). So, the total downgoing wavelet can be characterized as the summation of the original wavelet, $\boldsymbol{w}_s$, and its ghost wavelet, $\boldsymbol{w}_g$, (Lindsey, 1960):

$$\boldsymbol{w} = \boldsymbol{w}_s + \boldsymbol{w}_g, \tag{1}$$

$$= \boldsymbol{w}_s + \alpha_s \boldsymbol{M}_s \boldsymbol{D}_{\tau_s} \boldsymbol{w}_s, \tag{2}$$

where $\boldsymbol{w}$ is the total wavelet in the time domain, α_s is the reflection coefficient of the air-water discontinuity above the source, $\boldsymbol{M}_s$ is a modifier representing wave propagation from the source to the surface and then to the source, and $\boldsymbol{D}_{\tau_s}$ is a time delay operator by an amount of τ_s.

Due to sea surface imperfections, its reflection coefficient can be both frequency and slowness dependant and also could be influenced by a cosine factor for a non-vertical ray path. The value of α_s does not influence the convergence of the proposed algorithm, however, for simplicity, in this paper, we assume that the air-water discontinuity is a perfect flat reflector and that the water layer, above the source, does not modify the ghost wavelet, then we have $\alpha_s = -1$ and $\boldsymbol{M}_s = \boldsymbol{I}$, where $\boldsymbol{I}$ is an identity matrix.

Accordingly, Eq. (2) can be written as:

$$\begin{aligned} \boldsymbol{w} &= \boldsymbol{w}_s - \boldsymbol{D}_{\tau_s} \boldsymbol{w}_s, \\ &= \boldsymbol{g}_s * \boldsymbol{w}_s, \end{aligned} \tag{3}$$

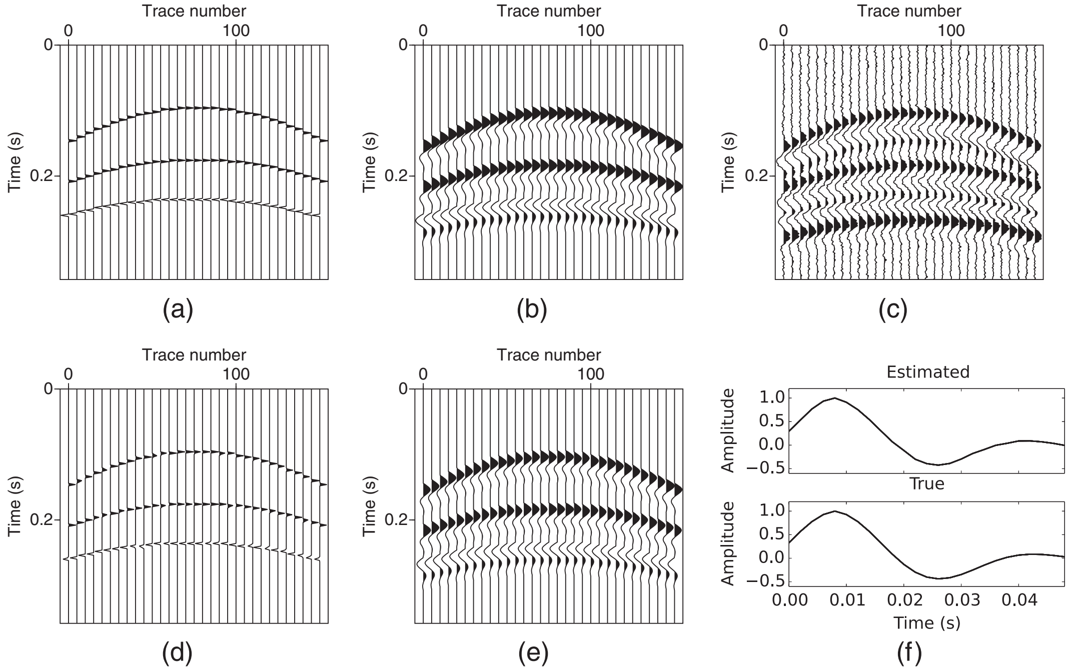

Fig. 2. Impulse response of a flat-layer earth model (a), the noise and ghost free shot gather corresponding to the model (b), which is contaminated with source side ghost and random noise (c). (d) The obtained impulse response of data after deconvolution, (e) the deghosted gather, obtained by using the proposed algorithm. (f) Comparison of the true and estimated synthetic wavelets.