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Receiver deghosting in the *t-x* domain based on super-Gaussianity☆

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ABSTRACT

Deghosting methods in the time-space (*t-x*) domain have attracted a lot of attention because of their flexibility for various source/receiver configurations. Based on the well-known knowledge that the seismic signal has a super-Gaussian distribution, we present a Super-Gaussianity based Receiver Deghosting (SRD) method in the *t-x* domain. In our method, we denote the upgoing wave and its ghost (downgoing wave) as a single seismic signal, and express the relationship between the upgoing wave and its ghost using two ghost parameters: the sea surface reflection coefficient and the time-shift between the upgoing wave and its ghost. For a single seismic signal, we estimate these two parameters by maximizing the super-Gaussianity of the deghosted output, which is achieved by a 2D grid search method using an adaptively predefined discrete solution space. Since usually a large number of seismic signals are mixed together in a seismic trace, in the proposed method we divide the seismic trace into overlapping frames using a sliding time window with a step of one time sample, and consider each frame as a replacement for a single seismic signal. For a 2D seismic gather, we obtain two 2D maps of the ghost parameters. By assuming that these two parameters vary slowly in the *t-x* domain, we apply a 2D average filter to these maps, to improve their reliability further. Finally, these deghosted outputs are merged to form the final deghosted result. To demonstrate the flexibility of the proposed method for arbitrary variable depths of the receivers, we apply it to several synthetic and field seismic datasets acquired by variable depth streamer.

1. Introduction

In a marine seismic survey, the receivers record not only the desired signals (the upgoing waves), but also their ghosts (the downgoing waves), which arise from a very strong reflection at the surface. The sea-surface ghosts that constructively and destructively interfere with the desired signals, causes frequency notches and attenuation of low frequencies, which in turn reduce the resolution of the recorded seismic data (Jovanovich et al., 1983). There are a number of deghosting techniques developed for conventional and non-conventional marine acquisition systems. These processing-based deghosting methods designed for conventional towed streamer data are often applied in different domains, among which are frequency-wavenumber (*f-k*) domain (Aytun, 1999; Vershuur et al., 1992; Liu and Lu, 2016), τ-p domain (Ray et al., 2013; Wang et al., 2013; Grion et al., 2015), frequency-space (*f-x*) domain (Mo and Lu, 2009; Zhou et al., 2012), and *t-x* domain (Amundsen et al., 2013; Robertsson and Amundsen, 2014; Lu et al., 2015; Yilmaz and Baysal, 2015). Since deghosting methods used in data processing can potentially be difficult, some non-conventional marine acquisition methods are also developed, such as dual-sensor streamer method (Carlson et al., 2007; Tenghamn et al., 2007), over/under towed streamer method (Posthumus, 1993; He et al., 2013), and the variable-depth streamer technique (Soubaras, 2010). Soubaras (2010) uses variable depth streamer where variable receiver depths along offset helps to achieve a marine broadband solution. Post-stack and pre-stack deghosting methods which are based on joint deconvolution (Soubaras, 2010; Soubaras, 2012) are proposed to remove the receiver ghosts in the variable depth streamer method. In the recent years, some processing-based deghosting methods are also developed for seismic data that are acquired by non-conventional marine streamers (Lu et al., 2015; Yilmaz and Baysal, 2015; Masoomzadeh et al., 2015).

In general, almost all existing deghosting methods adopt a ghost-generation model and rely on the estimate of the ghost parameters. The ghost-generation model that includes two parameters: the sea surface reflection coefficient and the time-shift between the upgoing wave and its ghost, is widely used (for example, Lu et al., 2015; Yilmaz and Baysal, 2015; Masoomzadeh et al., 2015). In practice, the sea surface reflection coefficient might be frequency- and angle-dependent (Masoomzadeh et al., 2015). For simplicity, some deghosting methods

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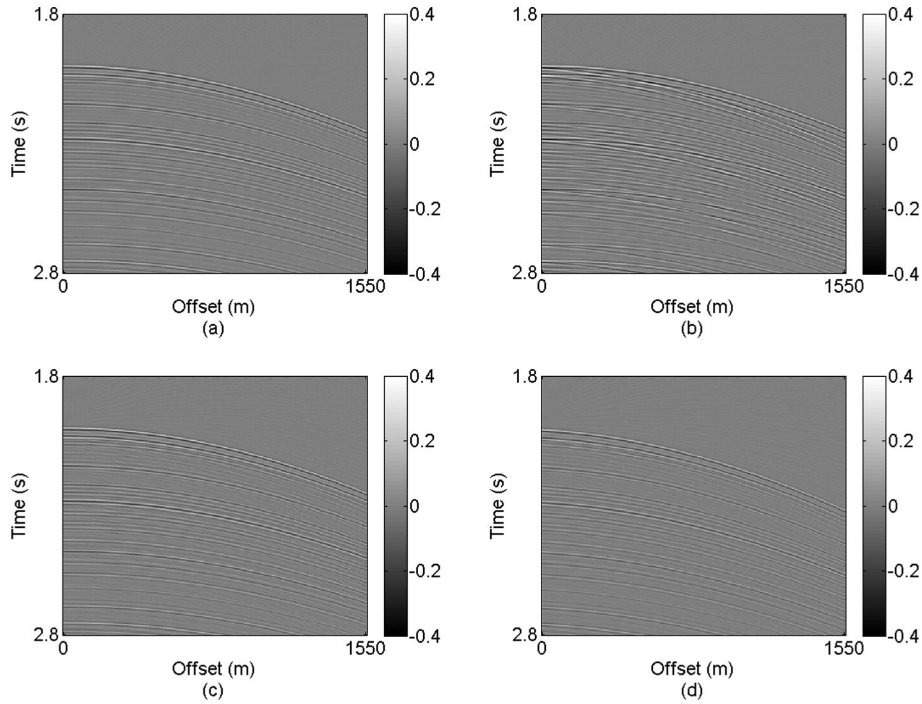

Fig. 1. The first synthetic seismic data example. (a) The true upgoing waves; (b) the seismic shot gather consisting of the upgoing waves and their receiver ghosts; (c) the deghosted result obtained by the SRD method; and (d) the polarity reversed ghost (panel c–panel b).

adopt a frequency-independent reflection coefficient. Regardless of the ghost-generation model used, the main challenge is how to find a reliable estimate of the ghost parameters. It is well known that seismic signal has super-Gaussian distribution (Walden, 1985). Super-Gaussianity of seismic data has been successfully used as a criteria for multiple attenuation (Guitton and Verschuur, 2004; Lu, 2006; Liu and Lu, 2008; Li and Lu, 2013; Liu and Lu, 2015), deghosting (Mo and Lu, 2009; Grion et al., 2015; Lu et al., 2015; Liu and Lu, 2016), phase estimation (Van der Baan, 2008; Van der Baan and Fomel, 2009), and so on. For seismic deghosting, the super-Gaussianity of the deghosted output is used as a criterion to obtain a reliable estimate of the ghost parameters (Mo and Lu, 2009; Grion et al., 2015; Lu et al., 2015; Liu and Lu, 2016).

In this paper, we extend the abstract (Lu et al., 2015) by providing more theoretical details and experimental results. In the proposed method, we adopt a ghost-generation model with frequency-independent sea surface reflection coefficient, and estimate the ghost

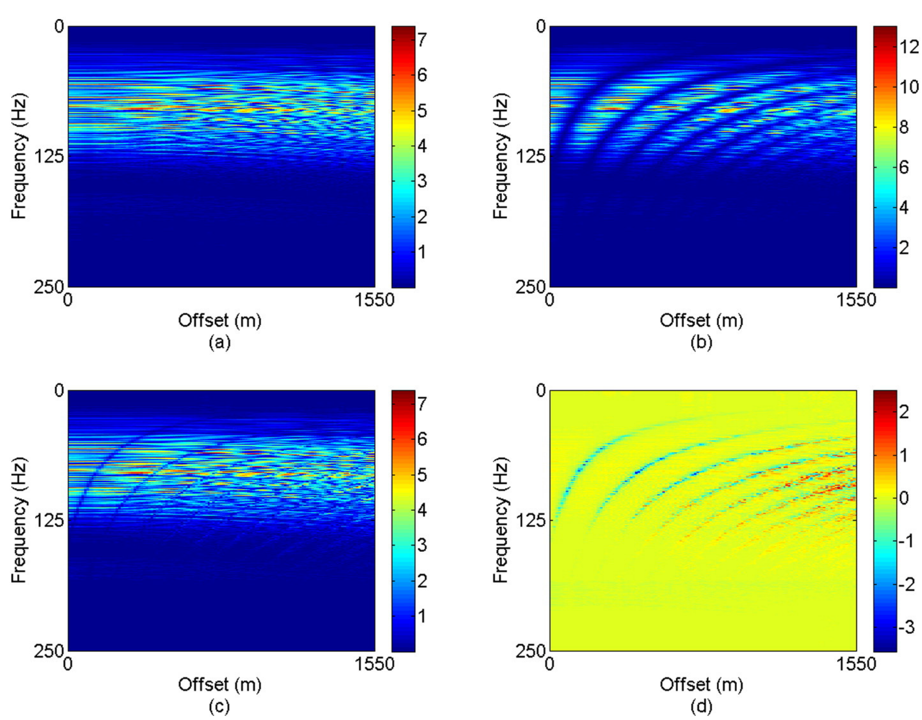

Fig. 2. The first synthetic seismic data example. The *f-x* amplitude spectra of (a) the true upgoing waves; (b) the shot gather; and (c) the deghosted shot gather. Panel d shows the differences between panels a and c.