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Far-field Source Signature Reconstruction Using Direct Arrival Data

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SUMMARY

For accurate source designature it is fundamental to have precise knowledge of the seismic far-field source signature. While near-field hydrophone data can often be used to provide good quality signatures, such recordings are not always available. This paper describes a technique to extract the far-field signature from the inversion of direct arrivals present in the seismic streamer data. The method has been applied to a deep water survey offshore Gabon, and has been found to produce comparable results to those using data recorded from near-field hydrophones mounted above the air guns on the seismic source array. The method presents advantages for the reprocessing of legacy surveys to achieve a more broadband seismic result.

Introduction

Far-field designature is an important stage in the processing of marine data, whereby a far-field source signature is converted into the required output wavelet. Traditionally a designature operator would be designed to remove the bubble from the far-field signature followed by zero-phasing of the remaining energy. While this remains an effective method to prepare the data for further processing and interpretation, it leaves the free surface source ghost in the data, thus narrowing the potential bandwidth of the dataset. With modern broadband processing it is increasingly common to compensate for the source ghost as part of the far-field designature process to reveal as much of the Earth response as possible. This may be achieved by designing a filter to shape directly from the far-field signature to a zero phase broadband spike, while at the same time limiting the amount by which the signal can be boosted in the low frequency and source ghost notch regions of the amplitude spectrum. Recent use of broadband sources with guns at more than one depth (Siliqi et al. 2013) have somewhat mitigated issues arising due to sharp shot ghost notches. The use of variable depth streamers, with a resulting diversity of receiver ghost notches (Soubaras 2010), has also reduced the problems associated with receiver deghosting.

The design of a suitable designature operator with the desired effect requires the availability of an accurate representation of the far-field signature. In the past, far-field signatures were usually generated using a modelling package, such as Nucleus (PGS) or Gundalf (Oakwood Computing Associates Ltd). A more accurate approach can be used to measure or extract the far-field signature from a direct recording in the field. Ziolkowski et al (1982) described how near-field hydrophones positioned within a source array may be used to derive a far-field signature, which has been used to carry out designature to good effect in a large number of studies, for example see Poole et al. (2013). Such an approach tends to produce better debubbling results than the use of a modelled far-field signature.

The method described by Ziolkowski is a powerful technique to derive far-field signatures where near-field hydrophone recordings have been taken. However, for legacy surveys these are unlikely to be available, and even for more recent surveys, it is not always the standard practice of every acquisition to measure gun signatures in this manner. Nevertheless the requirement for an accurate far-field signature with which to carry out designature still remains.

In this paper we describe a method that can be used to determine a far-field source signature from the direct arrivals in the streamer data. The method is suitable for deep water surveys and has been applied to a survey offshore Gabon.

Theory

Ziolkowski (1982) and Parkes (1984) described an equation relating the signal recorded in near-field hydrophones, mounted on the source array, as a function of notional sources, by:

$$h_i = \sum_{j=1}^{m} \frac{1}{r_{ij}} n_j \left(t - \frac{r_{ij}}{V_w} \right) + R \sum_{j=1}^{m} \frac{1}{r_{ij}^g} n_j \left(t - \frac{r_{ij}^g}{V_w} \right),$$

where h_i is the recording for near-field hydrophone i in the source array, n_j is the notional source for gun j in the source array, t is the time, r_{ij} is the distance between near-field hydrophone i and gun j, V_w is the water velocity, R is the reflection coefficient at the water surface, and $r_{ij}{}^g$ is the distance between near-field hydrophone i and the virtual gun j representing the free surface ghost. A notional source is a hypothetical isotropic point source signature representing an individual gun in the source array, but taking into account the bubble interactions that occur when all of the individual air guns in the source array fire together. The relationship between the near-field hydrophones and notional signatures is a simple linear relationship, which is apparent by writing the equations in the frequency domain, where the time shift is converted into multiplication by a complex exponential term. The equations may be solved using a least squares method. The vertical far-field signature may then be calculated from a superposition of the notional sources plus the effect of the surface ghost.

For a direct arrival, the same equations described by Ziolkowski hold if h_i represents the signal recorded at channel i of the streamer cable instead of the i^{th} near-field hydrophone recording. However, although the equations may easily be written down in this situation, the problem is ill conditioned. In the near-field environment we have a wide range of distances r_{ij} between the individual guns and near-field hydrophones in the source array, ranging from about 1 m, being the distance between an individual air-gun and its closest near-field hydrophone, to around 24 m for the distance between the guns and hydrophones at diagonally opposite corners of a standard source. These cover a wide range of azimuths, which leads to a well-conditioned set of linear equations. Unfortunately for direct arrivals the scale of the distances involved (the first channel in the streamer being approximately 150 m from the source) means that if we write down the equations relating the individual guns in the source array to the channels in the seismic streamer, the equations are ill-conditioned and we cannot resolve each notional gun signature. However, if we assume that the source array is represented by a single notional source, then we are able to invert to this from the direct arrival data.

An important issue to be considered in the algorithm is the array effect, for both the receiver and the source. Generally in a streamer cable, each recording is the sum of a number of point hydrophone instruments spaced along a short distance of the cable; the hydrophones making up a receiver array to minimise noise in the recording and suppress aliasing. This does not present any difficulty when considering seismic reflection data, as the source signature for the near channels corresponds to a near vertical far-field. However, the direct arrivals hit the start of the streamer at a similar depth to the source array, corresponding to a propagation angle of approximately 90 degrees. This means that there is a small time shift in the arrival time between the signals arriving at each point hydrophone. The effect of averaging the signals over the receiver array is to progressively dampen the signal in the amplitude spectrum as the frequency increases. The receiver array is modelled in the inversion by representing each streamer channel as the sum of point hydrophone signals spaced along the cable.

A second array effect is due to the positions of the guns. As the source array consists of a number of airguns arranged along several parallel strings, a similar effect to that taking place in the receiver array is observed, due to the time shift in the signals being emitted from each airgun at a propagation angle nearing 90 degrees. As per the receiver array, the effect is the dampening of the signal at higher frequencies. In figure 1 we illustrate the source and receiver array effects. As the direct arrivals are inverted for a single notional source representing the source array, the source array effect must be removed before the far-field is calculated. This is done by assuming that the single notional source is positioned at each gun position in the source array but scaled with a factor of the cube root of the gun volume, which is proportional to the gun amplitude, see Vaage (1983). This takes the source array effect into account, even though we cannot resolve each single notional source from the data.

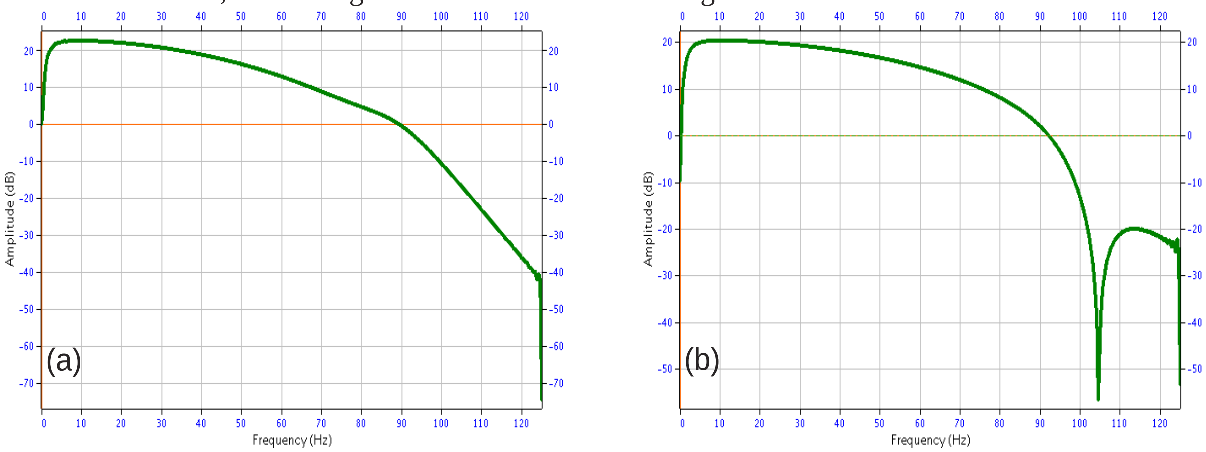

Figure 1 *(a) Source array effect, (b) receiver array effect, in the frequency domain*

Real data example

The methodology has been tested on a dataset acquired offshore Gabon, with water depths varying from 90 m to 3000 m. For this survey, near-field hydrophone data were also recorded, and have been used to generate a far-field signature with which to compare against the far-field signature extracted from the direct arrival data. Twenty consecutive shots were selected in the deep water region of the survey, to ensure that the direct arrivals were clearly separated from seismic reflection data. The first ten channels of each shot were then selected. The direct arrival data were inverted to find the far-field signature using the method formerly described, taking into account shot and receiver array effects. Figure 2 illustrates the direct arrivals in a shot gather showing the bubble present.

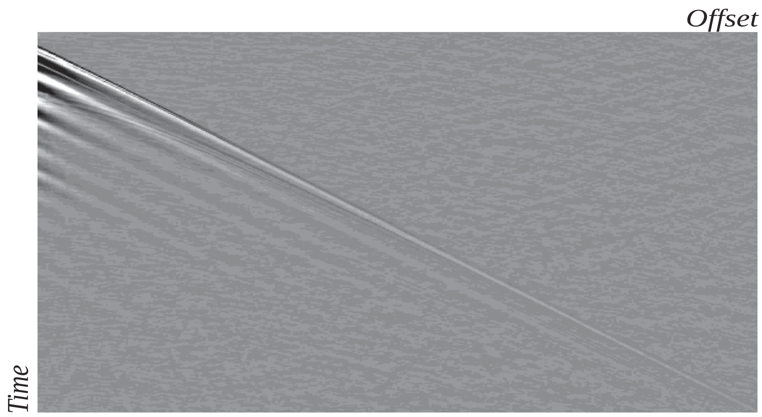

***Figure 2** Direct arrival in a shot gather*

The vertical far-field signatures extracted from both the near-field hydrophone data and the direct arrival data, in both the time and frequency domain, are illustrated in Figure 3. Note that the two far-fields are broadly similar. The vertical far-field signatures were then used as a starting point from which to design the designature filters, by shaping to a zero phase broadband spike, with suitable restrictions on the level by which the signal can be boosted in the low frequency and ghost notch regions.

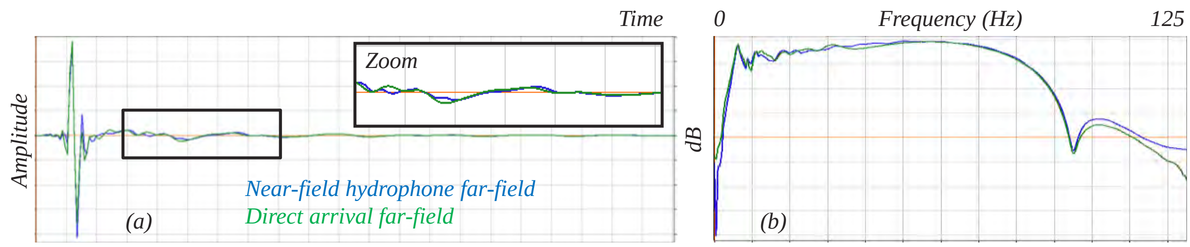

***Figure 3** (a) Far-field signatures from near-field hydrophone data and direct arrivals, (b) amplitude spectra of far-field signatures compared*

Figure 4 presents a set of shot gathers, with 4(a) showing the gather before any designature filter is applied, 4(b) showing designature using the far-field signature extracted from the near-field hydrophones, and 4(c) illustrating the results of designature with the far-field signature from the direct arrivals. In general, the designature results from either far-field signature are broadly comparable. Figure 5 illustrates the common channels before designature and after the application of each of the derived designature filters.

Conclusions

A method has been derived to extract a vertical far-field signature from direct arrival towed streamer data. The idea is an extension of Ziolkowski's near-field hydrophone equations to streamer data with source and receiver array effects included. The far-field found in this way has given comparable designature results to those achieved using a far-field derived from near-field hydrophone recordings.

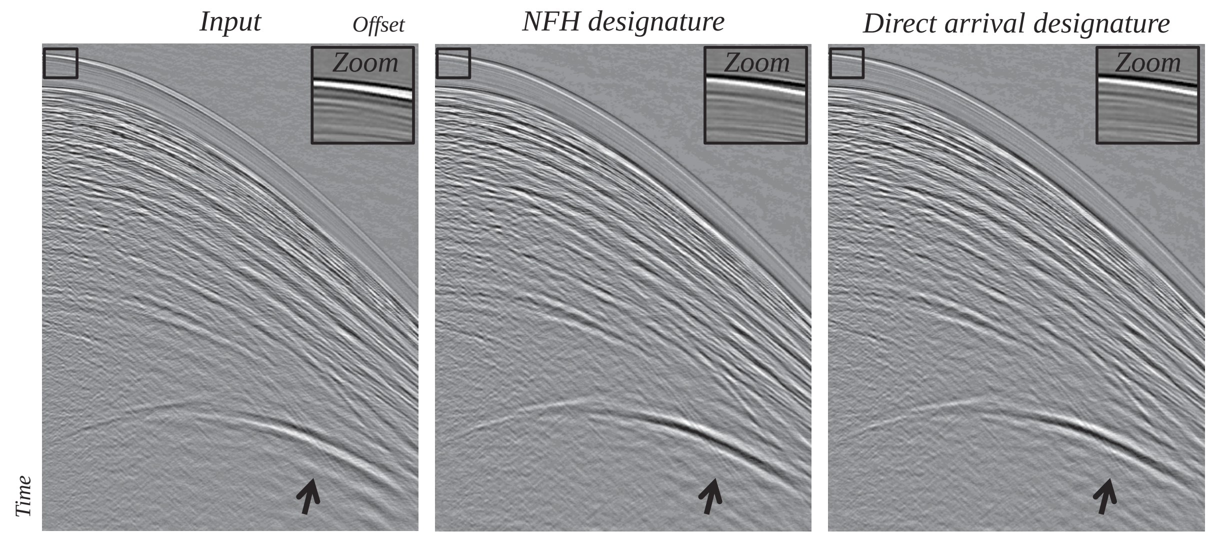

Figure 4 *(a) Shot gather prior to designature, (b) after designature using far-field signature from NFH, (c) after designature with far-field signature from direct arrivals*

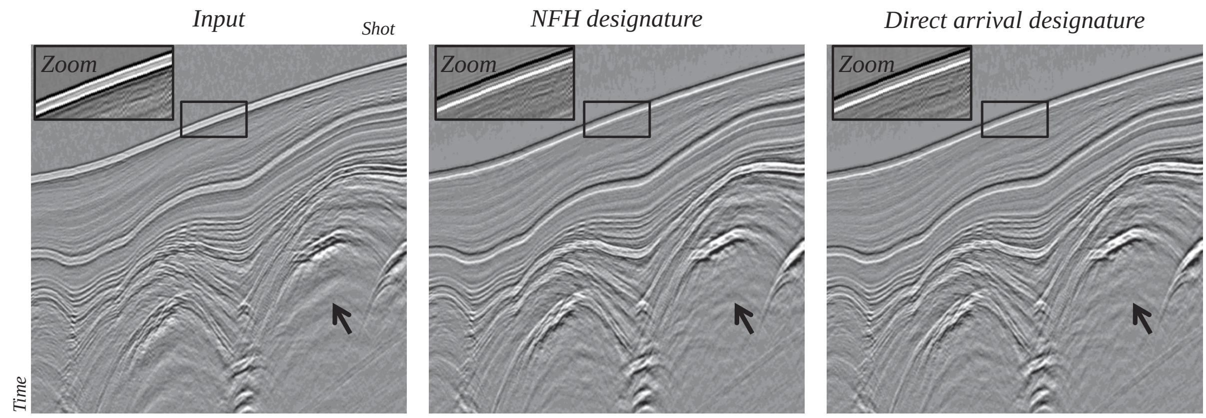

Figure 5 *(a) Common channel section prior to designature, (b) after designature using far-field signature from NFH, (c) after designature with far-field signature from direct arrivals*

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