Compressive sensing based design for land and OBS surveys: The noise issue

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Summary

Two important developments in seismic acquisition in the last decade were introduction of simultaneous shooting and reconstruction via inversion of the complete seismic wavefield. As the seismic wavefield is typically under sampled in at least one of the four spatial coordinates, both developments could contribute to improve the sampling and, in addition, to increase acquisition efficiency.

Herein, we look at the impact of seismic noise when simultaneous shooting and seismic wavefield reconstruction are implemented for a land or ocean bottom seismic survey.

Introduction

Simultaneous shooting for land acquisition was introduced on large scale commercial applications in 2008, 2009 and 2011, when Independent Simultaneous Shooting-ISS (Howe, 2008), Distance-Separated Simultaneous Shooting (DS3) (Bouska, 2009) and Managed Spread and Source (MSS) (Quigley, 2011) were introduced. These methods require to use many vibrators (10 to 30), a large receiver spread to allow distance separation, and an open field, with a minimum number of obstructions. These requirements restricted the use of these methods to the Middle East, and recently, to Alaska.

For Ocean Bottom Systems, cables (OBC) or nodes (OBN), ISS method started to be used in 2011 (Alexander, 2013) and, since then, several surveys were acquired in different areas.

The benefits of simultaneous shooting for land and OBN were remarkable in terms of improved source sampling and acquisition efficiency.

Compressive sensing (CS) was developed in the applied mathematics community around 2005 (Candes et al., 2005) and introduced to the seismic world in 2007 (Hennefent and Herrmann, 2007; Herrmann, 2010). According to CS theory a signal that was not sampled based on the Nyquist rule, and is aliased, can be completely recovered if: the signal was randomly sampled, and the signal can be mapped, via a mathematical transform, in a certain domain, where it has a sparse representation.

The theoretical framework of compressive sensing incorporates simultaneous source separation and wavefield reconstruction in a single processing step.

Seismic surveys were acquired for ocean bottom cable, towed-streamers and land based on compressive sensing designed that included simultaneous source acquisition and wavefield reconstruction (Mosher et al., 2017).

Seismic data acquired on land or in shallow water could be contaminated with strong seismic noise. If simultaneous source acquisition was employed for these surveys we must perform simultaneous source separation and wavefield reconstruction (interpolation). It could be tempting to do this in one step, but the risk is to compromise the result with interpolated noise, remnant from source separation. Herein, we discuss the data processing options available to address this issue.

The effect of random sampling on aliasing

The classical illustration of the effect of random sampling on aliasing is shown in Figure 1. If the signal is sampled acording to Nyquist (Figure 1a) the representation in Fourier domain has few significant coeficients (sparse representaion). If the signal is 3-fold undersampled, but uniformaly sampled (Figure 1b), "aliased" coefficients are present in the Fourier domain and creates an ambiguity. If the signal is 3-fold undersampled but with random sampling, the sigificant coefficients can be recovered (Figure 1c). The aliasing noise is part of the background noise.

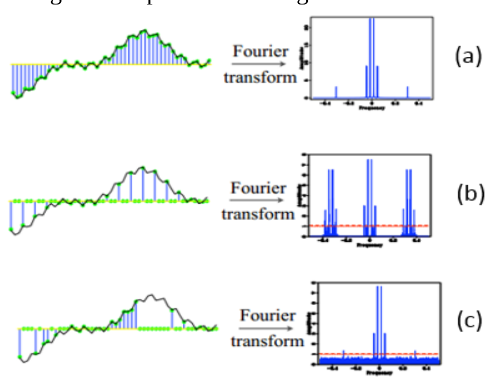


Figure 1: Random sampling in compressive sampling (Courtesy Seismic Laboratory for Imaging and Modeling, University of British Columbia

To see how this translates to seismic we simulated a shot with uniform receiver distribution (Figure 2a) and with random receiver distribution, but fewer receivers (Figure 2b). The ground roll is aliased because receiver sampling is not as required by the Nyquist rule. We generated the FK music spectra for both shot gathers and it can be seen that for uniform sampling is difficult to identify the ground roll main modes due to the aliased ground roll. For the shot gather with random receiver sampling the FK-music spectra are cleaner because the alised ground roll becomes part of the background noise. This feature could help to do a better modeling and subtraction of the ground roll from the data acquired with random sampling. Interpolation of data will also benefit from random sampling (Mosher et al.,2017)

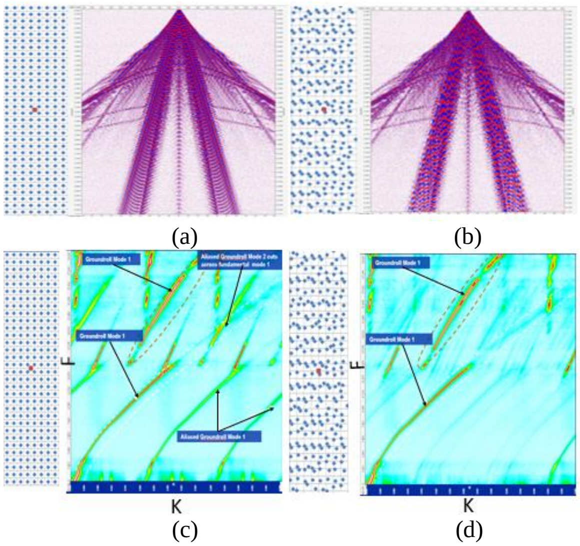


Figure 2: The effect of random sampling on aliased groundroll: synthteic gathers with ground roll with uniform sampling (a), and with random receiver sampling (b) ; Fk-music spectra of shot gathers with uniform sampling (c), and with random receiver sampling (d)

Noise effect on compressive sensing acquired data

Seismic land or OBS acquisition can be designed based on compressive sensing with or without simultaneous shooting. In most of land and OBS acquisition, the sampling of sources and receivers is not adequate for ground roll or for Scholte waves. Based on compressive sensing we can interpolate the data to a finer sampling interval that will properly sample the noise. However, if the ground roll is very strong, the result of interpolation will have artifacts that will be difficult to remove afterwards. To illustrate this we generated a synthtetic shot record, with reflections and ground roll sampled at 50 m receiver interval, with a maximum frequency of 40 Hz (Figure 3a). The FK-spectrum of this shot shows that the data is severely aliased (Figure 3b). We interpolated the record to 25 m receiver interval and the result is shown in Figure 3c and the spectrum in Figure 3d. The spectrum shows no aliasing. This means that the ground roll can be attenuated using methods like FK-filtering. However, interpolation of the strong ground roll generated artifacts that affected the signal, particularly at near offsets. If the attenuation of the ground roll can be performed based on methods that are not sensitive to aliasing, the interpolation can be done after noise removal. A powerful method to attenuate the ground roll, even when is aliased, is based on modeling and subtraction of the surface waves (Strobia et al., 2010).

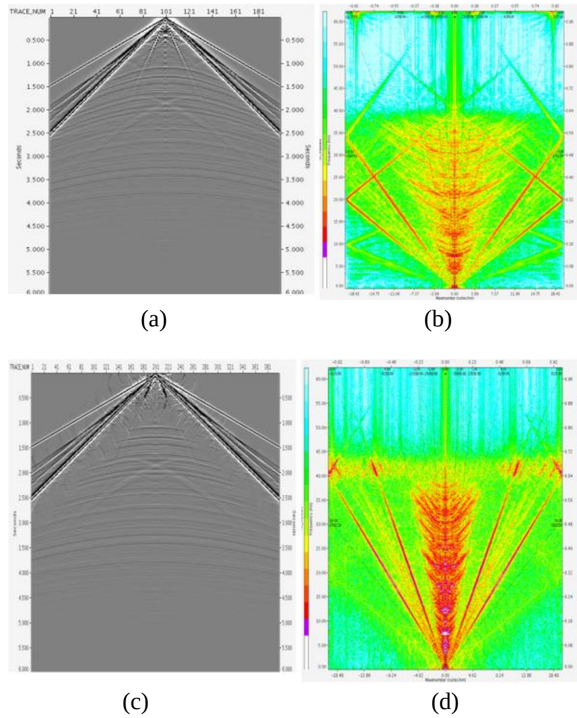


Figure 3: Shot record with reflection and ground roll 50-m sampling (a) and corresponding Fk_spectrum (b); record interpolated to 25 m and (c) and the FK spectrum (d)

If simultaneous shooting and interpolation are incorporated into land and ocean-bottom seismic compressive sensing design, the noise issue is more critical. Although the compressive sensing theory allows to perform simultaneous source separation and interpolation in one single step, this is not reccomended when level of seismic noise is high. The best way to handle this is to separate the sources, attenuate the noise and perform interpolation.

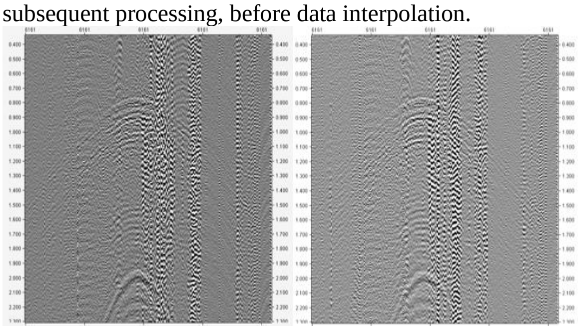
There are two classes of methods used in current processing practice for simultaneous source separation:

a) Methods based on “seismic interference” attenuation, where signal separation from the desired source is achieved by attenuating the signal received from the other sources, in one processing domain where the desired source signal is coherent and the signals received from the other sources are incoherent.

b) Methods based on modeling and inversion: the model is defined based on Radon, curvelet or other transforms, where data has a sparse representation, and the inversion algorithms that are used are based on sparse-inversion (Moore, 2010).

Both type of methods, in many instances, do not separate accurately the interfeering sources, particularly when "strong on week" signals interfere, and this data requires extra noise attenuation, otherwise the noise will be spread out by interpolation.

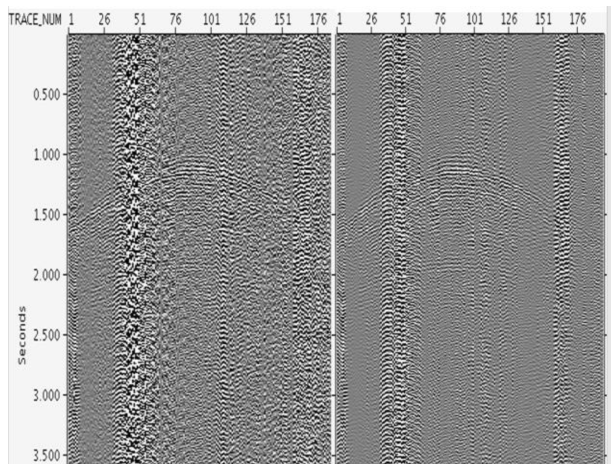
The simultaneous shooting method used in acquisition could be designed to protect the signal from the subsurface target by using DSS or MSS type methods. Another possibility to minimize the effect of seismic interferences for vibroseis acquisition is to encode the sweeps (Moldoveanu et al., 2017). One way to encode the sweeps is to divide the conventional sweep in N orthogonal segments that have different frequency content and different phase. The length of each segment is L/N seconds, where L is the length of the conventional sweep (in seconds). The number of segments corresponds to the number of vibrators sweeping simultaneosuly on N shot points. At each shot point each vibrator will sweep N sweep segments, which are different. The deblending process consists in correlation with the proper sweep and vertical stacking of the sweeps generated on the same shot point. In Figure 4a we show an example of vibroseis shot record, after correlation with the 20-s conventional sweep, acquired during a conventional land survey in West Texas. In Figure 4b, we display a record acquired with 4 vibrators shooting simultaneously with encoded sweeps, each sweep of 5-s length, after source separation. It can be seen that in both records, there is noise not related to the shot point that must be attenuated in subsequent processing, before data interpolation.



(a) (b)

Figure 4: Vibroseis shot record acquired with conventional shooting (a), and vibroseis shot record acquired with four vibrators sweping simultaneously, with encoded sweeps, after simultaneous shot separation (b)

For the encoded-sweep vibroseis simultanoeus shooting there is a possibility to reduce the level of seismic noise if a reduced number of sweep segments are randomly generated on each location (Kumar et al., 2018). For instance, if two sweeps per location are generated instead of four sweeps, the noise level will be reduced. In Figure 5a four sweep segments were generated on the same station, corelated with the proper sweep, and vertically stacked. In Figure 5b only two segments were generated on the same location, correlated and vertically stacked and, as a result, the noise level is lower. Compressive sensing can be used to recover full bandwidth reflectivity at each vibrator location. However, the noise issue still remains and must be solved before we perform source separation and inversion in one step. Work is in progress to demonstrate this on a small 3D dataset acquired with simultaneous encoded sweep in West Texas.



(a) (b)

Figure 5: Encoded sweep shooting with four segments per location (a), and with two segments randomly selected for each location (b).

Compressive sensing design for a land survey: a synthetic study using the SEG Seam-II Barrett model

The SEG SEAM II Barrett unconventional model was designed to represent shale reservoirs in North America midcontinent basin (Ragone et al., 2017). The model is 10 km x 10 km x 3.75 km (X,Y,Z), with a grid size of 6.25 m x 6.25 m and depth step of 6.25 m. Based on this model, we created a larger model by mirror imaging the original model in x and y directions and by using a grid size of 12.5 m in X, Y and Z. The size of the new model has a dimension of 40 km x 40 km x 7.4375 km and will allow us to simulate realistic types of land seismic surveys. A North-South view through this model is shown in Figure 6. The features of the near surface are quite complex and generate geologic noise from near-surface scattering.

The acquisition geometry we consider is pictured in Figure 7. The receiver patch (blue) consists of eigh receiver lines with 25-m receiver and line interval, 720 stations per line. The source patch is a grid of 100 m x 100 m , 60 stations on each line. Both, sources and receivers could be randomized.

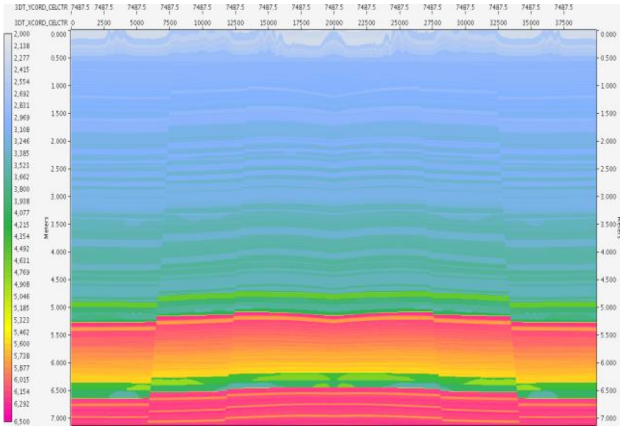


Figure 6: A North-South view through the SEG SEAM-II Barrett unconventional model

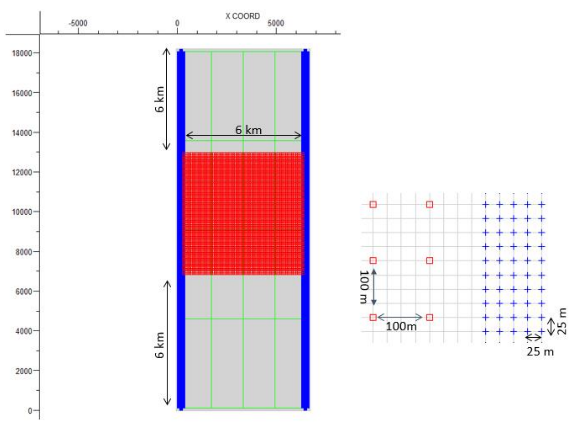


Figure 7: Source and receiver patch for the acquisition geometry analyzed in this study; this geometry will be randomized

The study objectives are to determine if compressive sensing methodology will perform for this geometry:

- Randomly decimate the receivers from 25 m x 25 m to 50 m x 50 m and interpolate back (increase acquisition efficiency)
- Randomly decimate the sources from 100 m x 100 m to 140 m x 140 m and interpolate back (increase acquisition efficiency)
- Interpolate the receivers to 12.5 m x 12. 5 m (higher resolution imaging)
- Interpolate the sources to 50 m x 50 m (higher resolution imaging)
- Implement simultaneous source shooting (increased acquisition efficiency) and analyze noise effect

Discussion and conclusion

The method we plan to use in this study is reconstruction of the seismic wavefield via low-rank matrix factorization (Kumar et al., 2013). This requires us to analyze the distribution of sources and receivers Sx-Rx vs. Sy-Ry, to determine if population is appropriate to interpolate the desired source and receiver grid. An example of Sx-Rx vs. Sy-Ry for the proposed geometry when the patch was rolled with 200 m, only in X-direction, is shown in Figure 8. The yellow area shows where each receiver is surounded by a source grid of 18 km x 12 km, and where full benefit of interpolation can be achieved

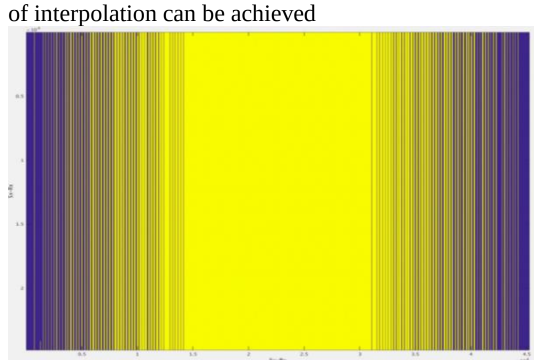


Fig 8: Sx-Rx vs Sy-Ry source and receiver organization

We discussed the effect of randomization on aliased ground roll data, which enables more accurate modeling of the ground roll and subtraction from the data. We showed that if we attempt to interpolate the ground roll, artifacts will be generated that will affect the signal.

When simultaneous shooting data is acquired, noise attenuation is more critical and requires to separate the sources, attenuate the noise and interpolate the data. The simsource separation and interpolation cannot be performed in a single step. Designing simultaneous shooting acquisition to minimize the noise effect on the target will improve seismic wavefield reconstruction.

Aknowledgements

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