Toward an Automatic Swell Noise Attenuation Process

M. Bekara* (PGS - Petroleum Geo-Services)

SUMMARY

Swell noise attenuation is the first step in the processing sequence of marine seismic data. Often this filtering requires a good amount of testing to achieve optimal results, particularly when swell noise characteristics vary considerably along the survey. In the context of on-board processing this filtering is the bottleneck of the production sequence. It would be very useful both technically and economically if there exists a solution that automate this process. This paper proposes a data driven method for swell noise attenuation. It is based on improving the detection of swell noise by deriving its characteristics from the data. The filtering parameters are automatically tailored to suit the spatial and temporal frequency spread of swell noise in each filtered gather. When compared to a conventional method, it gives similar results but with much less testing effort. It is highly data adaptive and can be used to attenuate gathers with different noise level using the same minimal parameterisation.

Introduction

Swell noise attenuation is an essential processing step in the delivery of acquisition-based broadband marine seismic data. Often this filtering is done on board the acquisition vessel for operational reasons. Current solutions for swell noise attenuation work by applying a de-spiker in the frequency-space (F-X) domain over local time-space (T-X) windows that cover the input seismic section. These windows are filtered independently and then merged to construct the output filtered gather. Each (T-X) window is mapped to the (F-X) domain and processed in two steps. First, the locations of swell noise in the (F-X) spectrum are detected. Second, the detected noisy samples are scaled-down or filtered using prediction error filters (Canales, 1984). Noise detection is the bottleneck of the solution and most of the testing is done to tune this step.

Often due to the complexity and the intensity of swell noise, the filtering solution is applied in cascade several times both in the shot and in the channel domain to achieve desired results. In the context of on-board processing, where time and resources are constrained, this proves to be challenging because there is a need of extensive testing due to multiple passes. There is also a need to restart the testing cycle whenever swell noise characteristics vary significantly with the change in the weather condition. All this may slow-down the production process of the field deliverable on board the acquisition vessel. In addition to that, swell noise filtering in domains other than the shot domain is not suitable for new acquisition strategies that relays on randomized simultaneous sources shooting. The reason for that is potential risk of signal distortion because source separation is often formulated as a denoise problem in domains different from the shot domain.

For the above reasons, one can appreciate the need for a robust swell noise attenuation solution that works only in the shot domain and in a data driven way to account for the variation of swell noise characteristics. This paper proposes a method to achieve this objective.

Proposed method

Before describing the proposed automatic method for swell noise attenuation, let's start by highlighting two main weaknesses of current swell noise attenuation methods:

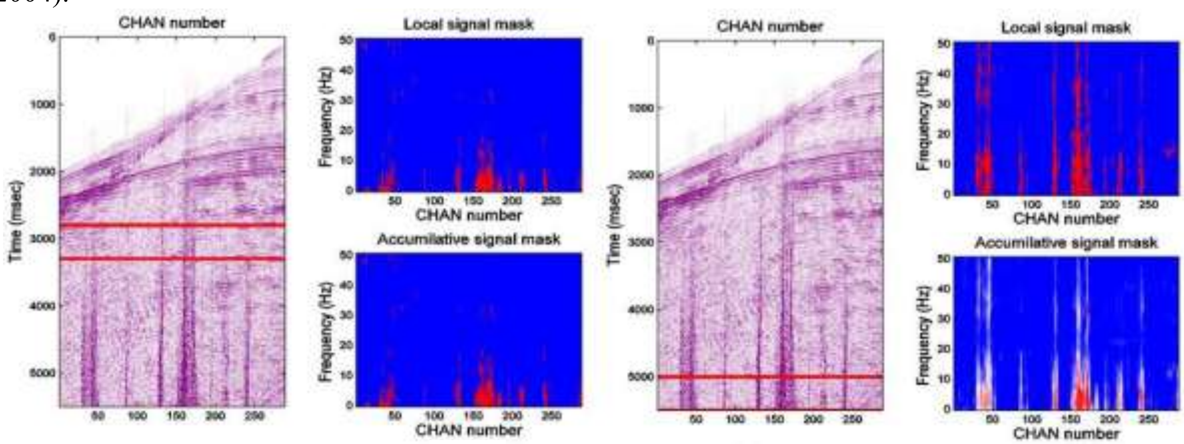
1. All local (TX) windows in the filter are processed independently. There is no coordination between these windows in terms of noise detection. If a given trace in a window is considered noisy, there is no guarantee that the same trace that falls in an adjacent window will be considered noisy too. This contradicts the fact that swell noise contaminates an entire trace from time zero to the end of the record. The lack of consistency in the detection of noise is the main reason behind signal distortion. Large signal amplitudes such as direct arrivals in the shallow part of the gather are mistakenly considered as swell noise because of their strong energy.

2. The detection of noise is improved by increasing the dimension of the processing window, i.e. the number of traces and the number of samples in each trace of the window (more statistics, better spectral resolution). However the filtering performance using F-X prediction or any other models does not enjoy such property because they assume local signal modelling. Since the detection step and the filtering step are done in the same T-X window, this grouping creates a trade-off for the user in terms of optimal parameter setting.

Improving the detection of swell noise is the way to improve the filtering performance. Conventional methods relay on the user to supply a threshold factor to compute an amplitude threshold for noise detection and this detection is done locally. This paper alternatively proposes a solution that is based on deriving a global F-X signal mask for each gather, i.e., to find which traces are contaminated with swell noise and which frequencies in those contaminated traces the noise is present. Only the noisy locations are filtered. Potential advantages of the proposed noise detection are:

1. Noise detection is done globally, i.e., it is disjointed from the noise filtering step so there is no trade-off in terms of finding good parameterisation.
2. A global signal mask would lead to a better signal preservation as non-noisy traces will not be affected by the filtering.
3. The possibility to adapt the spatial window size for the filtering as a function of frequency for a better signal interpolation.

The derivation of the signal mask is done over a portion of the seismic gather where the signal to swell noise level is low. A local T-X window that includes all the traces in the gather is extracted (Figure1-a). It is mapped to the F-X domain and each frequency slice is then processed individually. The process consists of detecting abnormal large amplitudes by using a data-driven statistical method to find outliers (Bekara et al. 2010). A local signal mask is derived by assigning a value of "1" if noise is detected and "0" otherwise (Figure 1-b). An accumulative signal mask is created when the fist T-X window is processed and it takes the values of the local mask (Figure 1-b). As the processing window slides down the section, the detection method is repeated as described above and a new local mask is computed (Figure 1-c,d). The accumulative signal mask is updated at each step. The processing window stops when it reaches the end record of the gather (Figure 1-c). The values in the accumulative signal mask (Figure 2-a) represent the frequency-of-occurrence that a given bin the F-X domain is contaminated by swell noise. A final frequency signal mask is derived by thresholding the accumulative mask (Figure 2-a). Once the signal mask is derived, then only those noisy frequencies in the noisy traces are filtered and the rest is left untouched. The signal mask can also be used to automatically derive the window length (number of traces) used for the filtering in each frequency by considering the value of this parameter proportional to the maximum clustering length of noisy traces (Figure 2-c). In this way, the only parameter that the user need to supply is the time window length, which for swell noise less than 15Hz can be defaulted to 500 milliseconds. The prediction filter order is set to a default value of 5, or alternatively estimated using a model selection criterion (Bekara, 2004).



(a) (b) (c) (d)

Figure 1 *The process of deriving the FX signal mask as the analysis window scrolls over the noisy gather.*

Data example

The proposed solution is compared to a standard flow for swell noise attenuation on different lines. Figure 3-a shows a set of gathers with moderate swell noise contamination. The result of using the standard production flow is shown in Figure 3-b. The standard flow consists of applying several passes of an F-X de-spiker with prediction error filtering interpolation both in the shot and in the channel domain (Schonewille et al. 2008). On the other hand, the proposed method consists of applying a single pass of the new solution with automatic parameter determination. The result of the proposed method is shown in Figure 3-c. Despite the good performance of the standard flow, it required a good amount of testing. The new method produced comparative results with a better attenuation of swell noise through the water bottom at far offsets, however with much less testing time. In the context of on-board processing, testing is a large proportion of the project timeline. The proposed method would allow less time in denoise testing and more time for further stages of processing.

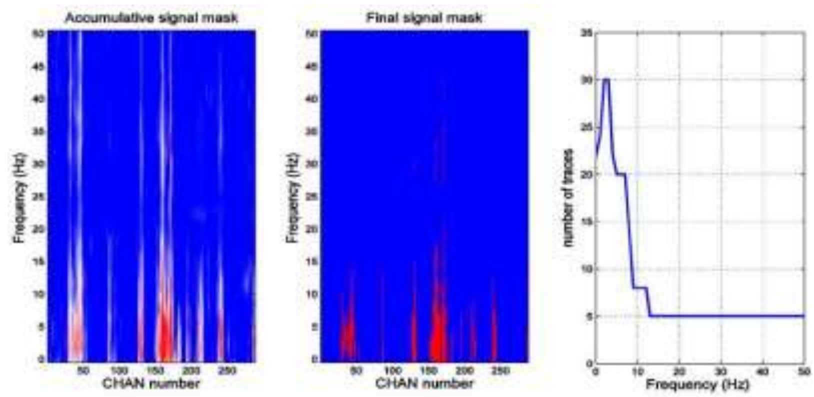
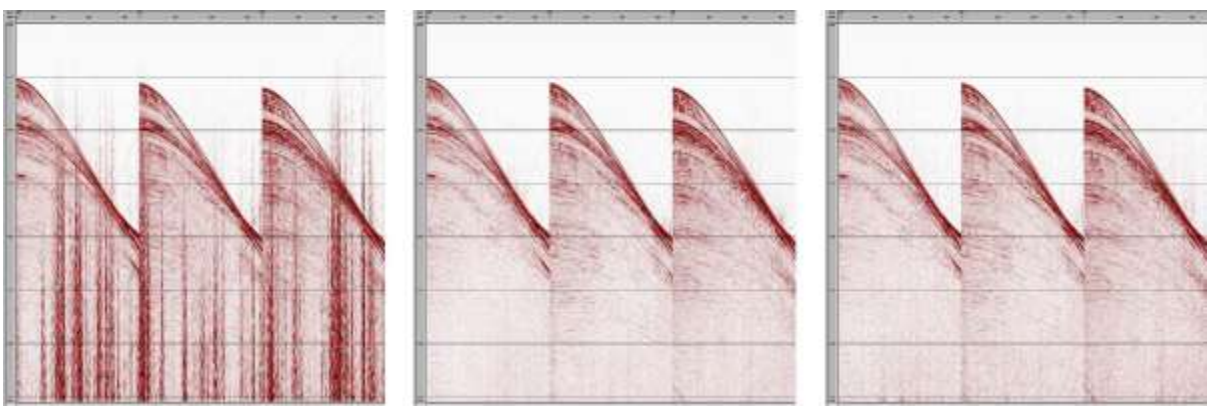


Figure 2 *The signal mask (b) is derived from the accumulative signal mask (a) by thresholding. Optimal spatial window length(c) can be derived from the signal mask*

To investigate the robustness of the proposed method in terms of automatic parameter adaptation, it is tested on two different lines with different noise characteristics. No parameters were set, except the time window length and the order of the prediction error filter. Parameters such as spatial window length and noise threshold factor which are key parameters in the standard methods are adaptively determined from the data. A set of seismic gathers with strong band of turn noise are shown in Figure 4-a. Turn noise has similar characteristic to swell noise and they are removed using the same methodology. The mew solution was adapted with minimal testing to prevent any signal attenuation. The turn noise was completely removed revealing the seismic interference that was hidden beneath it (Figure 4-b). No signal distortion is visible (Figure 4-c). Figure 5-a shows a set of gathers contaminated by a weak level of swell noise. The same solution with identical parameters to the one used for the previous example was used on this dataset. The result of the filtering is excellent (Figure 5-b). The difference section (Figure 5-c) shows no signal distortion. This indicates that the proposed method has a good level of adaptation with respect to variation of the noise characteristics.

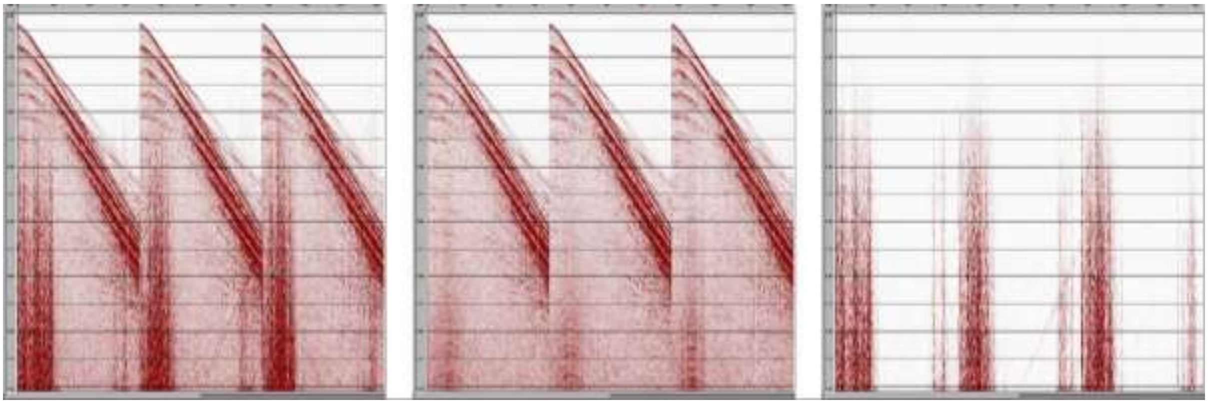


(a) (b) (c)

Figure 3 *Performance comparisons. Noisy input data (a), after several passes of standard denoise in the shot domain and in the channel domain with extensive testing (b), using the proposed method (c).*

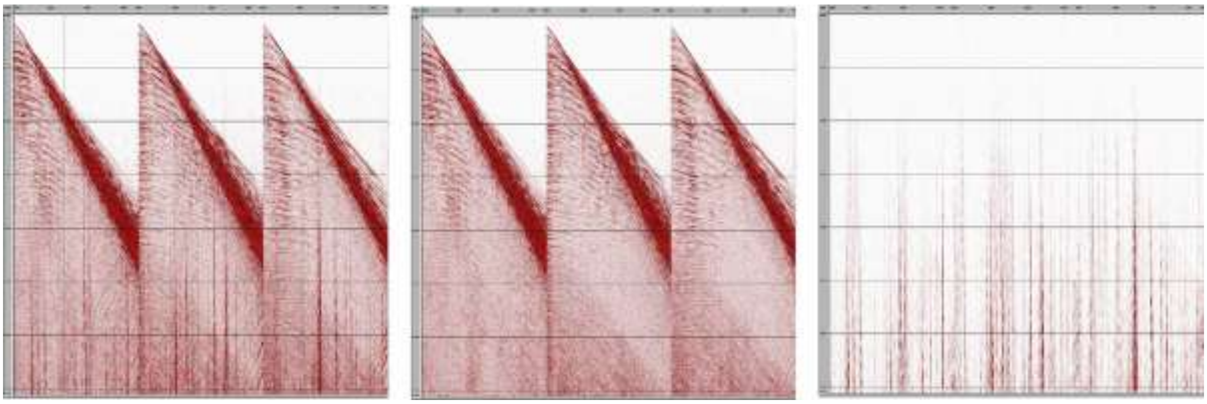
Conclusions

This paper presents an innovative method for swell noise attenuation that is based on automating the noise detection step. It also separates the noise detection and noise filtering steps, therefore leading to



(a) (b) (c)

Figure 4 *Shot gathers with strong band of turn noise present (a), result of applying the proposed method (b) and difference section (c).*



(a) (b) (c)

Figure 5 *Shot gathers with a mild band of turn noise present (a), result of applying the proposed method (b) and difference section (c).*

no trade-off in optimal parameter selection. The proposed method is tested on real data sets and shows a great data adaptation with no user's interaction. Such a solution is very useful in the context of on-board processing where time and resources are limited. Reducing the testing time for denoise would allow more time for sub-sequent stages. The proposed solution when combined with an automatic sub-sequent QC step (Spanos et al. 2012) will improves the productivity of field deliverables on board the acquisition vessels.

Acknowledgements

The author would like to thank PGS for the permission to show the data and to publish this work. Special thanks to Tom Marsh for the compilation of the tests.

References

Canales, L (1984), "Random noise reduction", 54th SEG Annual International Meeting, 525-527.
Bekara, M. and Van der Baan M (2010), "High-amplitude noise detection by the expectation-maximization algorithm with application to swell-noise attenuation", Geophysics, 75, no. 3, V39-V49.
Bekara, M.,(2004) "A model selection criterion for small data record using the symmetric Kullback divergence", PhD thesis, University of Paris XI, France.
Shonewille, M; Vigner, A and Ryder A., (2008), "Advances in swell-noise attenuation", First break vol26, pp.103-108.
Spanos, A., and Bekara, M,(2012) "Using Statistical Techniques to Improve the QC Process of Swell Noise Filtering", 75th EAGE Conference & Exhibition incorporating.