Random seismic noise reduction using fuzzy based statistical filter

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Abstract: In this paper, a novel filter based on fuzzy logic and a statistical technique for seismic noise reduction is presented. The statistics, referred to as the rank ordered absolute differences is calculated within a sliding window and is used for recognizing noisy samples. At the same time, we took advantage of the flexibility of fuzzy logic concept to deal with noisy and incomplete data to calculate a fuzzy weight. The rank ordered absolute differences and two other statistics form the fuzzy inference system input. The output is a fuzzy weight which is included within the formula of the proposed filter. The synthetic seismic data were generated by the seismix unix open source program and a Matlab® code filtering has also been developed. Extensive simulation results indicate that the proposed filter achieves noise attenuation, increases the signal to noise ratio and improves significantly the visual appearance of the seismic data.

Keywords: Filtering, fuzzy logic, rank-ordered absolute differences, seismic data, statistics.

Introduction

Noise in seismic data has several sources, depending on whether it is coherent noise or random noise. In the later case, Yilmaz (2008) cited, among other things, wind motion, poorly planted geophones and electrical noise. The most common method for attenuating random noise is CMP stacking.

The frequency-wavenumber (FK) filter is also a very popular method for attenuating random as well as coherent noise. Other filters include domain transforms such as FX filter (Canales, 1984; Gulunay, 1986) or the Karhunen–Loève transform (KL) (Jones and Levy, 1987;AL-Yahia, 1991). There are, however, occasions when all these methods fail as with data sampled with non-uniform rate, low signal-to-noise ratio (Harris and White,1997) or spatial aliasing of coherent noise. In recent years, techniques drawn from biological domain such as artificial neural networks (ANN) and fuzzy logic have emerged and have been implemented successfully in seismic data processing (Essenreiter, 1999; Djarfour et al., 2008, 2014 Hashemi et al., 2008, Ferahtia et al., 2013). In this paper, we have designed a filter based on fuzzy logic and using a statistics called rank-ordered absolute differences (ROAD) (Garnett et al., 2005) for detecting and removing noisy samples. Preliminary results are very encouraging since they show the robustness and the effectiveness of the proposed filter in removing random noise even when the signal-to-noise ratio is very low.

A Short presentation of the ROAD statistic

The rank-ordered absolute differences statistic (ROAD) was first introduced by Garnett et al. (2005) as a means of removing noise from images. The ROAD statistic is calculated as follows: first, the absolute differences between a central sample and its neighbors are defined; then, these absolute differences are sorted in increasing order; finally, the four smallest values are added together. The result is that noisy samples would have large ROAD values, whereas noise-free samples would have small ROAD values. In other words, the ROAD statistic provides a measure of how close a central sample is to it four neighbors.

Why fuzzy logic?

The incomplete and noisy nature of the seismic data makes fuzzy logic more suitable to address this issue.

Fuzzy logic models human knowledge with simple fuzzy IF-THEN rules. First introduced by Lotfi Zadeh, fuzzy logic quickly showed efficacy and robustness in tackling difficult topics in different domains.

The filter's design

In this study, we implemented a fuzzy inference system where the rank ordered absolute differences and two other statistics form the fuzzy inference system input. The output is a fuzzy weight which is included within the formula of the proposed filter :

$$S_i=r_{kl}*exp(^{-3*w/var(\Delta j})\qquad (1)$$

where :

S_i : is the ith filtred sample

r_{kl} : is the raw sample extracted from an nxn sliding window

k,l : sample position within the shot gather

W : is the fuzzy weight which constitute the fuzzy inference system output.

var(.): is the variance

and Δ is the absolute difference between the central sample and its neighbor (j).

Results and discussion

Synthetic data were generated using the seismic unix program (CWP/SU) which consist in a single shot gather (Figure 1). Four distinct events can be distinguished at different reflection times. In order to test the capacity of the proposed filter in removing random noise, data of figure 1 was mixed with different percentage of random noise (Figures 2a and 2b).

The results of filtering corresponding to data corrupted by 10% and 20% random noise are shown in (Figures 3a and 3b). It is clear that the random noise identified in Figure 2 have been perfectly located and removed by our filter. Moreover, the signal of interest has been preserved. The difference section shows the noise part removed by our filter (Figure 4).

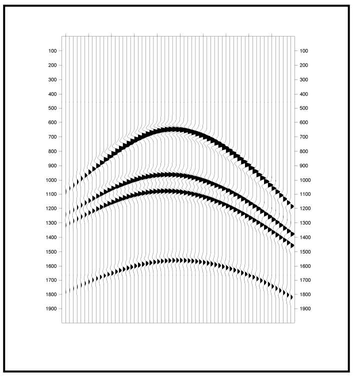

Figure 1. Noise-free synthetic shot gather

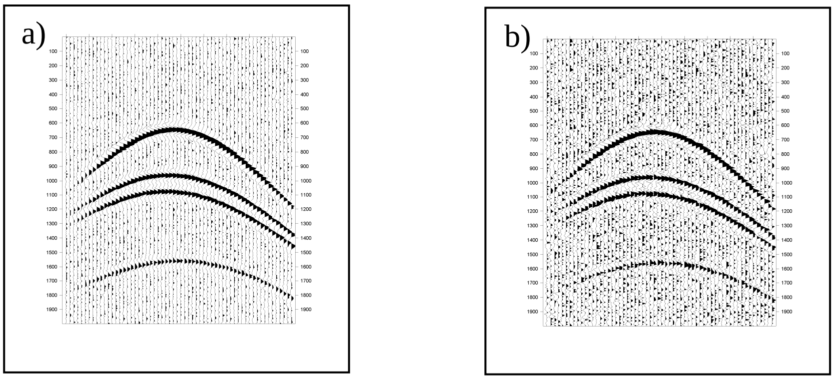

Figure 2. shot gather of figure 1 corrupted by a)10% random noise and b) 20% random noise

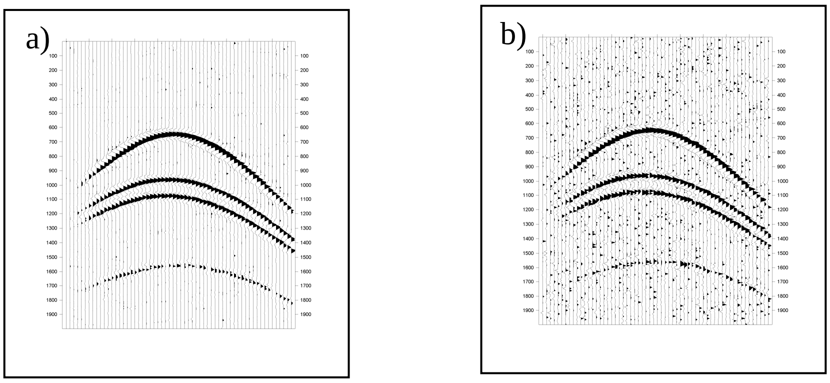

Figure 3. Filtering results in the case of a) 10% random noise and b) 20% random noise

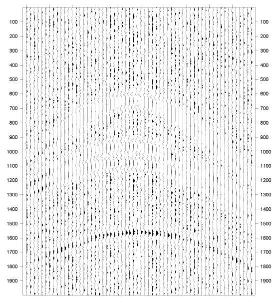

Figure 4. Difference shot gather.

Conclusion

In this work, a fuzzy statistic filter was addressed to filter seismic data. The results show that the filter successfully identified and removed random noise even when the background random noise reaches very high levels. The results show significant improvement of the SNR. One of the advantages of the proposed filter is that its parameters are easily tunable.

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