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Seismic Random Noise Attenuation via Non-Local Means Filters

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SUMMARY

Random noises corrupt the information contained in seismic data and in order to obtain more reliable information we have to attenuate them as much as possible. The majority of methods by using an appropriate transformation do this task. But in this paper we do not use any transformation domain and introduce two temporal/spatial filters named Bilateral and Non-local means. After comparative study of their performance on synthetic data, we address the problem of parameter estimation for the proposed filters and present a method to estimate the optimal parameters. The synthetic data test shows high performance of our method.

Introduction

We can define the recorded data as:

$$Y_{i,j} = X_{i,j} + e_{i,j} \quad (1)$$

where $Y_{i,j}$, $X_{i,j}$ and $e_{i,j}$ are recorded data, original data and Gaussian noise with zero mean respectively. Many different methods have been proposed for estimating $X_{i,j}$ from $Y_{i,j}$. Most of them use a special transformation domain to separate the coefficients of the noise from those of the signal, like F-X deconvolution and curvelet thresholding [4]. But, in this paper, no transformation is used for denoising. And we work with data in the original temporal/spatial domain.

Contributions of this paper are two fold: 1) comparison of the performance of two temporal/spatial filters named Bilateral and Non-local means (NLM) filters with a conventional transform domain filter (F-X deconvolution) and 2) introduce a method to find the optimum parameter for NLM filter.

Theory

The Bilateral filter was introduced in order to overcome problem of blurring the sharp edges in the images while using band- pass filters. This filter besides the weighted averaging (band-pass filtering) in each point, uses the similarity of nearby points. This added term prevents the recovered image to be blurred in the edges. This filter is defined as [2]:

$$X_p = 1/w_p \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(|Y_p - Y_q|) Y_q \quad (2)$$

Where $\|x\| = \sqrt{x \cdot x}$, $|\cdot|$ denotes the absolute value, w_p is normalization coefficient, Y_q is image amplitude, and G is the Gaussian function. Parameters σ_s and σ_r control the filter length, X_p is the denoised signal and $p, q \in S$ where S is the set of indices of the image.

In sum, Bilateral filter due to its locality in temporal/spatial, has some disadvantages. So, in order to overcome them, NLM filters was proposed as [2]:

$$X_p = 1/w_p \sum_{q \in S} G_{\sigma}(\|\Gamma_p(y) - \Gamma_q(y)\|) Y_q \quad (3)$$

where $\Gamma_p(y)$ and $\Gamma_q(y)$ are a window around pixels p and q (in image y) respectively. Centres of the windows are placed on p and q , G_{σ} is a Gaussian and $p, q \in S$ with S the set of indices of the image.

Parameter estimation

The Gaussian parameter (σ) in NLM filter, greatly affects the filter output and estimating that parameter is an important step in denoising of seismic data. Totally, this parameter could be considered as a function of noise level, i.e. the larger the parameter, the more the noise and vice versa. There are methods for parameter estimation in the context of inverse problems such as Discrepancy principle, L-curve, analysis SURE, GCV and (see Hansen [3] for the theories of them). Here following Almeida et al [1] we make use of whiteness of predicted noise. In this method the optimal parameter is supposed to result a white estimated noise. Procedure of this method is to normalize the predicted noise, calculating its auto correlation and then calculating its difference with Dirac delta (auto-correlation of an ideal random signal is Dirac delta function). The method is listed as below:

$$1) \text{ Normalize the estimated noise using ith parameter: } \hat{e}_i = \frac{e_i}{\text{var}(e_i)} \quad (4)$$

2) Calculate the auto-correlation of the estimated noise:

$$R_{\hat{e}_i}(m, n) = \sum_{j, k} \hat{e}_i(j, k) \cdot \hat{e}_i(j - m, k - n) \quad (5)$$

3) calculate the weighted difference of auto-correlation with Dirac delta to obtain the measure:

$$M_{RW}(\hat{e}_i) = \sum_{\substack{(m, n) = (-L, -L) \\ (m, n) \neq (0, 0)}}^{L, L} W(m, n) \cdot (R_{\hat{e}_i}(m, n))^2 \quad (6)$$

where $W(m, n) = \exp(-1.25(m^2 + n^2))$ is a weighting function and $M_{RW}(\hat{e}_i)$ is the measure for i th parameter. Minimum of this measure belongs to the most white estimated noise and hence optimum parameter.

Numerical tests

First we compare performance of NLM, Bilateral and F-X deconvolution filters on a synthetic data contaminated with Gaussian noise with SNR of 10 dB. Parameters of these filters are those that reconstruct the original image with minimum MSE. Results are shown in Fig. 1.

As it can be seen in Fig. 1, NLM filter has a higher performance regarding MSE in comparison with other filters. So in the next step we test the performance of the introduced parameter estimation method for NLMs filter. Fig. 3 shows the curves of MSE and equation 6 (parameter estimation measure) versus NLM filter parameter, for the synthetic example. As it can be seen, that the minimum of both curves occur in the same parameter with a good approximation. Fig. 2 shows original, noisy and denoised images and predicted noise using the parameter estimated by equation 6 that is plotted in Fig. 3.

Figure 1 Top, from left: original data, noisy data, Bilateral filter output, NLM filter output. Down, from left: f-x deconv output, bilateral filter residual, NML filter residual, f-x deconv. residual.

Figure 2 Top: Original image and noisy image. Down: Denoised and residual images using the parameter estimated in figure 3.

Figure 3 Blue: MSE curve vs NLM filter parameter, Green: equation 6 vs NLM filter parameter.

Conclusion

In this paper we compared performances of two temporal/spatial (Bilateral and NLM) filters and a transform domain (F-X deconvolution) filter and showed that NLM filter had a better performance in the sense of MSE for denoising seismic data. Also it was shown that the proposed parameter estimation method had a good performance while working with NLM filter.

References

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