Off-time denoising : is stacking the solution?

Analysis and non-parametric denoising

Technical report THEM2001-01
January 2001

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Report funded by **THEM Geophysics Inc.**

Introduction

This report assumes that the reader is familiar with **THEM Geophysics Inc**. THEM system is an innovative EM system appropriate for rough terrain mineral exploration. It was developed over the last 4-5 years and is still considered a prototype.

One of the unresolved issue has been the noise level. It is only one of several issues of course, but signal-to-noise ration seems to be a convenient way to measure the quality of an EM system and is of significant commercial interest. Unfortunately, there isn't a standardized measure of the noise level because processing software and hardware vary greatly from one system to another.

At this point in time, it seems that processing the signal itself (and not subproducts such as channels) might be a priority because there are qualified consultants able to prepare the various subproducts in a satisfying manner for the industry.

Data under consideration and warning

We will studying the file bob3.dat provided by THEM Geophysics Inc. The file is 217 Mbytes in size and dated from April 21st 1999. X and Z coils are available but only Z coil will be considered here. This analysis may not apply to all collected data by THEM EM system and the reader should be aware that there might be components in the signal which are specific to this particular file. It is however believed to be a representative signal set by **THEM Geophysics Inc.** It is assumed that the emitter was set at 30 Hz so that we have 60 half-cycles (or *frames*) per second and 512 samples per half-cycles (for a sampling rate of 30kHz) over both the X and Z coils.

Definition of the problem

Current EM processing software extract all of their information from the off-time of the signal, that is, the delay during which the emitter is turned off and the signal is decaying (more or less according to an exponential curve). It is also where the apparent signal-to-noise ratio is lower (it can be as low as 1:25).

Baseline correction is achieved through the SIMn algorithm using $n = 3$ and a late window of 48 samples (see [1]). Whenever stacking is not explicitely specified we stacked each two subsequent half-cycles (simply averaging one with the other after inverting the signs). This type of data will be refered to as “raw” since no denoising was used on it.

Our goal is to increase substantially the signal-to-noise ratio. The current implementation of THEM software achieve noise reduction through stacking[1] over 6 frames or more and using an experimental wavelet denoising scheme referred to as *DeSpike* (to remove noise due to sudden and brief atmostpheric discharges). This wavelet denoising scheme won't be discussed here even though it is important to handle atmospheric discharges in any future processing software.

Is stacking working ?

Since atmospheric discharges are relatively rare and very localized, the Despike algorithm discussed above won't increase in a measurable way the signal-to-noise ratio of the raw signal. Stacking is therefore the only denoising tool currently used to increase this ratio.

One important issue is therefore to determine whether stacking is an efficient way of reducing noise levels. If most of the noise is white, it is known that stacking over n frames will reduced the noise level by a factor of $1/\sqrt{n}$ therefore increasing the signal-to-noise ratio by a factor of $\sqrt{n}$.

The mathematical result concerning noise reduction through stacking can be demonstrated as follows, let f be the true value and $\varepsilon_1, \varepsilon_2\ldots$ be the (white) noise measured by the corresponding half-cycle (we assume local stationarity). If each ε_k has variance σ^2, then the sum of all n ε_k will have variance $n\sigma^2$ and therefore, the standard

1 Stacking means that we average the responses over n half-cycles (switching signs) and then use this averaged response instead of the x half-cycles (in effect, downsampling the signal by a factor of n). We can also replace the average with the median.

deviation of the noise will be $\sqrt{n}\sigma$ and the average (dividing by n) will be $\sigma / \sqrt{n}$.

Therefore, stacking over 6 half-cycles as is the standard procedure with the current implementation of THEM processing software would reduce noise by a factor of 2.4 so that an amplitude of 50 in the noise level would be reduced to 20.

However, looking at Fig. 1, 2 and 3 there is no such drastic noise reduction. While some reduction does occur, it is clearly not of the order we would expect. It means that one of our assumption about the type of noise is false. As we will demonstrate below, it appears that the noise is not white.

Figure 1. The raw data after baseline correction (*x* axis is in number of samples)

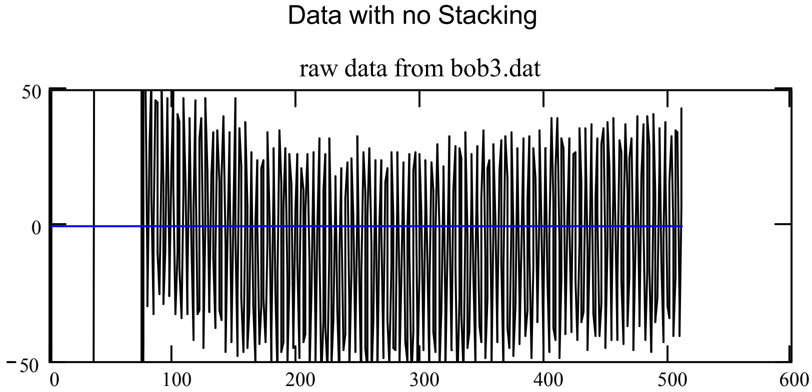


Figure 2. The raw data after baseline correction and 2 stacking. Notice that the noise reduction compared to Fig. 1 is not very significative. (*x* axis is in number of samples)

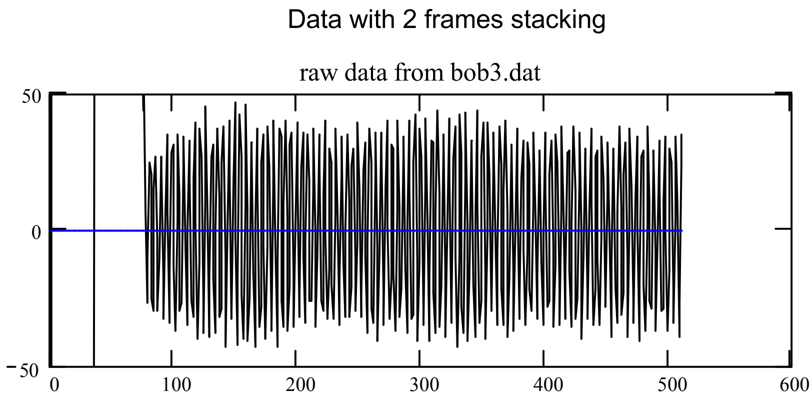
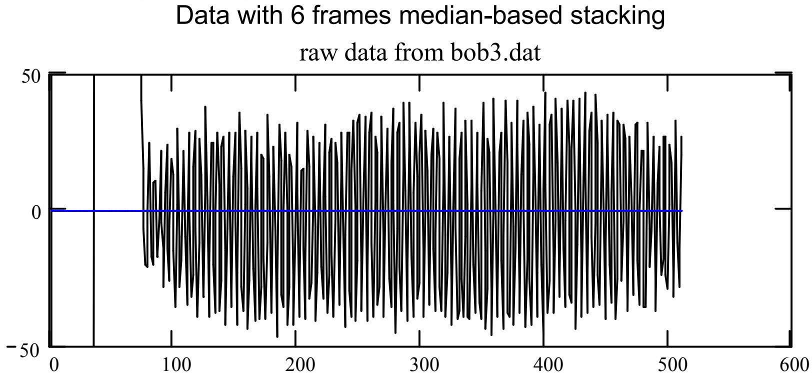
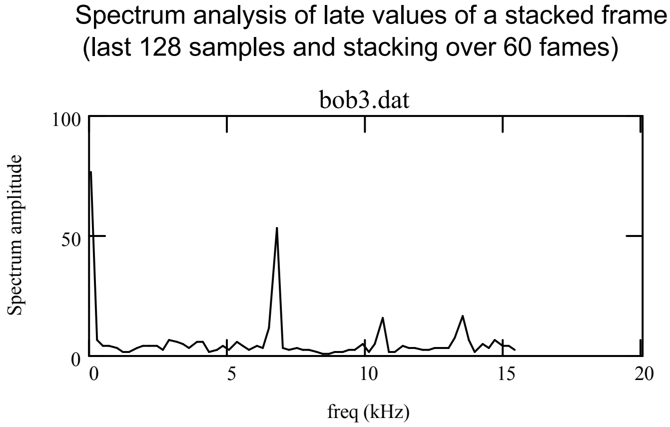


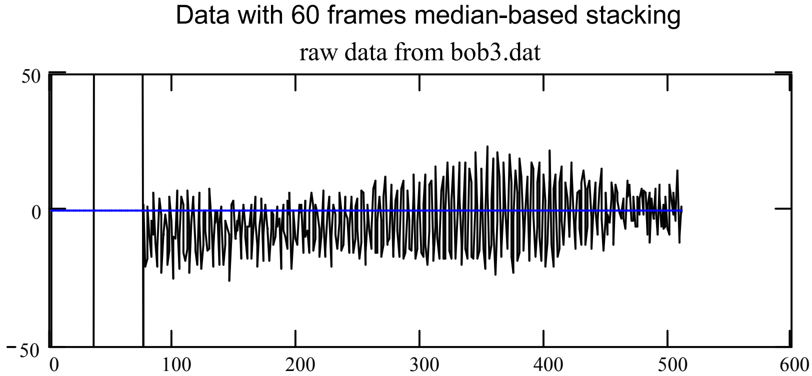
Figure 3. The raw data after baseline correction and 6 stacking. The noise reduction is barely noticeable with respect to Fig. 1 and 2. (*x* axis is in number of samples)



In Fig. 4, we stack over 60 half-cycles and compute the Fourier spectrum of the last 128 samples (out of the 512 samples contained in a half-cycle). It is clear from the Fourier spectrum that the noise we observe is not white. Moreover, we see that even after stacking over 60 half-cycles, the noise level is still very high (higher than expected with white noise).

Figure 3. Stacking over 60 half-cycles, we demonstrate that stacking is not an efficient denoising tool in particular because the noise isn't white but has a specific frequency signature.





Wavelet denoising

THEM has already a Wavelet Shrinkage denoising module which can be used to process and denoise the signal assuming we make the proper modifications, tuning, and research. Using the Wavelet Shrinkage algorithm with a short filter (Haar) and using what is referred to as "hard shrinkage", we get excellent noise reduction (see Fig. 4 and 5). A more elaborate demonstration is needed along with extensive testing but as shown in Fig. 5, results are convincing (decays are clearly visible while noise is not present). It should be noted that this type of denoising will not modify significantly the on-time data and doesn't rely on a model (it is essentially non-parametric denoising).

Figure 4. Using a stacked half-cycle (stacked over two half-cycles) and zooming in on the first few milliseconds of the off-time, we show that the denoised signal has a very low noise ratio while remaining true to the raw signal.

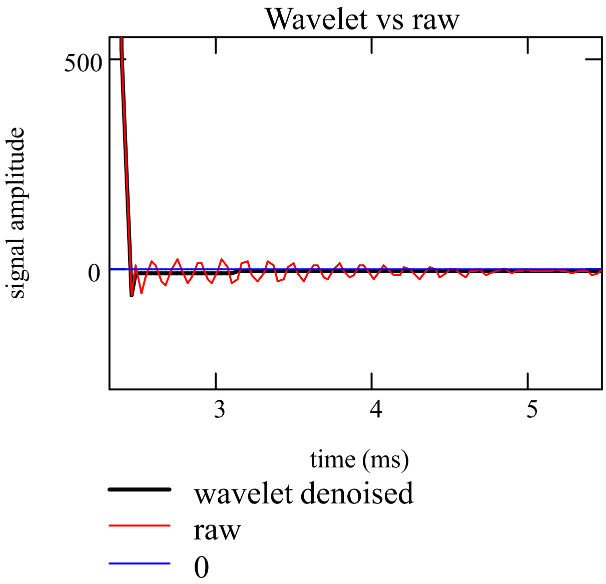
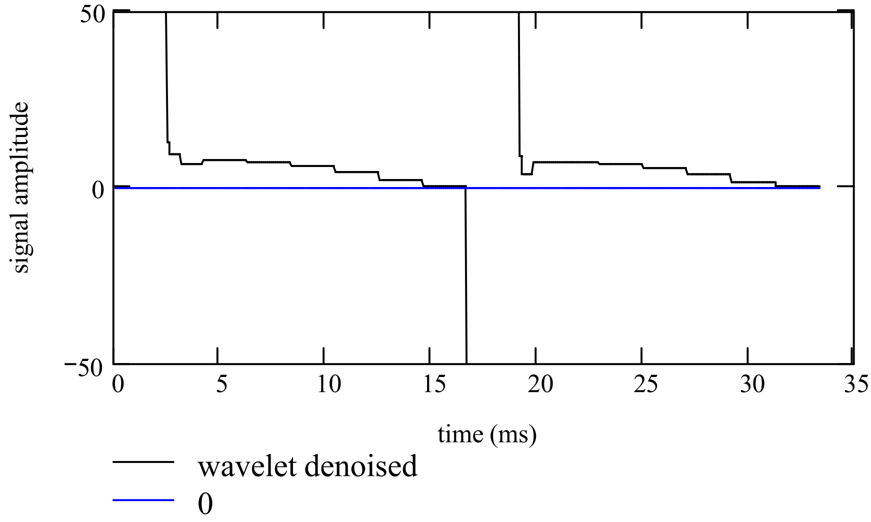
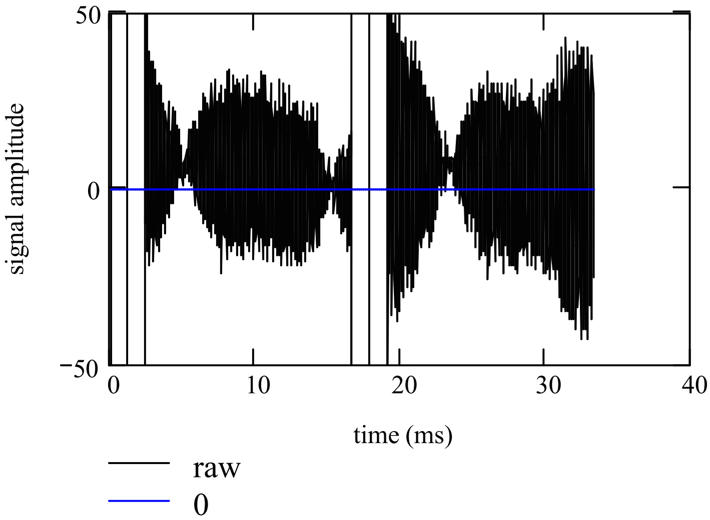


Figure 5. Comparison between several stacked half-cycles (stacking is set to two half-cycles). Below is the raw data and above is the denoised signal. Impulses (on-time) do not appear because of the scale.





Conclusion

Stacking half-cycles simply doesn't achieve the noise reduction we need. It is quite possible that the signal is polluted by hardware deficiencies such as bad shielding. Better software approaches are available and needed. More extensive testing is needed (over several files of data) and atmospheric discharges should be processed as well.

The author would like to thank THEM Geophysics Inc. for its support and funding.

References

[1] Daniel Lemire, *Rapport sur un nouvel algorithme de correction de la ligne de base pour THEM Geophysics Splines, interpolation des moyennes et moindres carrés (SIM),* Technical Report, Montreal, June 12th 1999.

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