Consistent Processing – A Linear Algebra View and Extensions

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Abstract

Redundancy is one of the most important features determining the success of seismic processing. Being able to efficiently make use of the whole redundancy available in any seismic survey seems then of fundamental importance.

Surface consistency has been explored for deconvolution, gain compensation, and noise bursts attenuation purposes for years. However, its use has been unnecessarily restricted to a limited set of survey components, namely, source, midpoint, receiver, and/or offset. In this paper we analyze the problem from a linear algebra point of view and try to extend the notion of consistency by the use of more general components appropriately chosen to make use of the redundancy noise and/or signal might have. A synthetic example demonstrates some of the conclusions drawn in this work.

Introduction

The whole set of measurements for a given time or frequency in a usual seismic survey forms an Ns X Nc dimensional space, where Ns and Nc are, respectively, the total number of shots and the total number of channels per shot. Let's denote this space by Ω. These measurements or traces belong to uniquely defined shots and receivers. A given shot is represented in Ω by a vector made up of *ones* only where samples belong to that shot and *zeros* elsewhere. Since a trace does not belong to more than one shot at the same time, the set of all shot vectors forms an orthogonal basis spanning a subset of Ω. Let's denote this subspace by ***S***. Analogously, the set of all receiver vectors forms an orthogonal basis that spans a subset of Ω here denoted by ***R***. Usually, two other less clearly related to acquisition subspaces are considered: ***O***, a subspace of Ω spanned by vectors characterized by offsets in specific ranges, and ***M***, a subset spanned by vectors characterized by midpoint coordinates belonging to specific bins defined in processing. Any pair of these subspaces (***S***, ***R***, ***O***, and ***M***) forms a linearly dependent set of vectors, and the smaller space that contains the whole set of vectors in ***S***, ***R***, ***O***, and ***M*** is itself just another subset of Ω. Let ***W*** stands for this subspace.

Surface consistent processing usually aims at mapping seismic data into each of these subspaces so as to reduce cross interference between shot, receiver, offset, and midpoint contribution estimations for the purpose of gain compensation, deconvolution, noise reduction, etc. Due to the great number of traces in a regular seismic survey, this mapping is usually carried out via the well-known Gauss-Seidel's iterative method. Clearly, only the subspace ***W*** of Ω will be subject to decomposition, and many features of Ω will be left off. This limitation may rather be a virtue, since it can represent a natural filter for undesirable seismic data features such as random noise.

Gauss-Seidel's method is known to converge to an answer for the problem of determining the weights each vector of ***W*** has in Ω. However, since the union of ***S***, ***R***, ***O***, and ***M*** is a Linearly Dependent (LD) set of vectors (Taner & Koehler, 1981), the answer of the problem is non-unique. A convenient solution, matching expected characteristics as, for instance, little variation of shot components along a line or reduced influence of coherent noise, is achieved in industry with a proper choice of the order each subspace of ***W*** (and then of Ω) appears during Gauss-Seidel's iterations. An extensive, empirical study on how to choose a clever order for specific purposes can be found in Farias(2001). Mathematically, Farias' recipes are based on the fact that in a Gauss-Seidel's iterative process with a LD set of vectors there will be an unfair dispute by the subspace represented by the intersection of ***S***, ***R***, ***O***, and ***M***. Those components that come first take it all.

Often desirable and/or undesirable seismic events show up with partial consistency in any of the spaces ***S***, ***R***, ***O***, and ***M***. It might be difficult in these cases to elect an adequate order for the terms appearing in Gauss-Seidel's method to accomplish free-of-noise and representative estimation of terms. The use of suitably designed extra terms would sometimes attenuate these problems if they could more favorably dispute these portions of the data.

A small shot and a synthetic 2D survey

Coherent noise may be restricted to limited regions in a real seismic survey and have poor consistency in most of the terms ***S***, ***R***, ***O***, and ***M***. To explore the idea of an extra term in Gauss-Seidel's method, designed so as to accommodate such events in a consistent way, a narrow-band low velocity coherent noise was added to 50 shots in a 300 shots synthetic 2D survey over plane reflectors. The maximum offset this noise can be seen was also limited to approximately half of the spread. Figure 1 shows 12 shots on the border between clean and contaminated shots. To simplify the analysis of the results, a wavelet with a broader and approximately flat spectrum was used for the signal.

A small shot defined to contain all contaminated traces was used during Gauss-Seidel's process to prevent regular shot terms to absorb contributions from the noise. This small shot has its spread limited to the largest contaminated offset. It is also defined only where shots

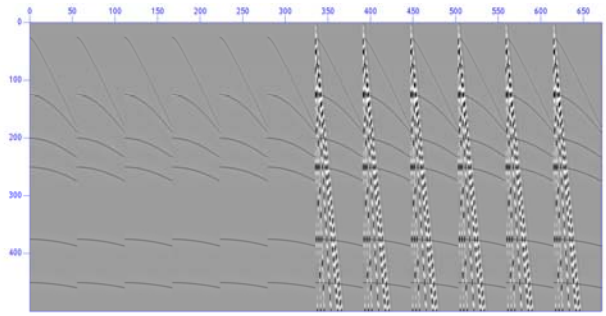

Figure 1 – *Twelve shots in the vicinity of the region where coherent noise appears*

are noisy. Defined this way, the components of the small shot are independent of all terms in ***W*** space. Thus, there will be no indeterminacy on which portion of the data will be captured by this component during Gauss-Seidel's process. The role of the small shot is to serve as a bin for the undesirable energy present in the data.

Gauss-Seidel iterations with and without small shots

The Gauss-Seidel process was set up to work out initially only the 4 components in ***W***, in the following order: regular shots, receivers, offsets, and midpoints. Figure 2 shows the shot component frequency spectrum just before and after the contaminated zone, after the first and the tenth iteration. As expected, regular shot terms

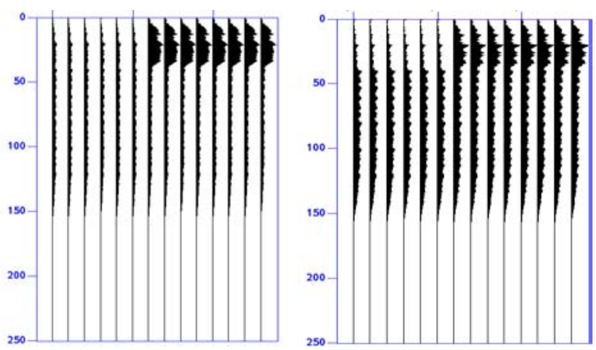

Figure 2 – *Frequency spectrum components just before and after the contaminated zone after the first iteration*(left) and *after the 10th iteration(right).*

tends to capture much of the noise. This would pose problems for deconvolution since the inverse filter would carry noise components into signal.

Gauss-Seidel's iterations were then carried out with the extra small shot terms. The order of computations was now the following: small shot, regular shot, receiver, offset and midpoint. Since noise is very consistent in the small shot term, much of it is captured by this term. Figure 3 shows the small shot term after the first and the tenth iteration. It is clear that most of it consists of a band-limited low frequency event. As mentioned earlier, the small shot terms are linearly independent of ***W***. Thus, changing the order of computations is not expected to alter the low frequency aspect of this term. However, since it has also captured contributions of other terms (the

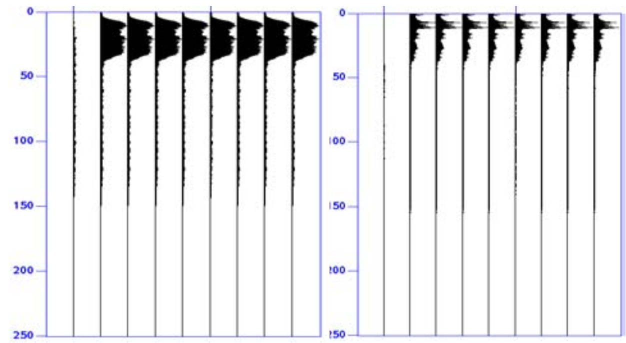

Figure 3 – *The small shot spectrum after the first (left) and tenth (right) iterations.*

projection of other terms into small shots) represented by ripples on the spectrum, changing the order may help to prevent signal information being captured by this term.

As iterations goes on, more energy migrates from regular shots to small shots and the other terms. Figure 4 shows the shot term after the first and the tenth iterations. It can be seen that this components show no more appreciable contribution of the band-limited noise in the contaminated area after the tenth iteration .

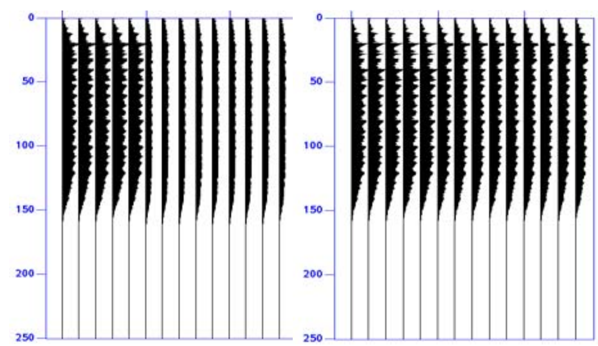

Figure 4 – *The regular shot spectra after the first (left) and the tenth (right) iterations.*

Comments

Despite the additive character of the noise, Gauss-Seidel's method developed a small shot spectrum that is supposed to represent the noise in a convolutional model. The apparent inconsistency is not a problem since the main objective is to free the regular shot and other terms of ***W*** from noise influence. At least in principle, there's is no interest in having a good description of the noise.

Other extra terms could have been devised for the same purpose. For instance, the traces covered by the small shot terms could also be covered in a limited offset term. Results using this limited offset term are qualitatively similar to ones presented here in what concerns to the cleaning of shot spectra.

Although the main focus of this discussion lied on the estimation of spectra, application of these ideas for gain compensation and/or bursts attenuation is straightforward.

Conclusions

An analysis of the linear dependence in a consistency problem may help identifying alternative terms for a more suitable distribution of the data energy. Upon exploring redundancy or the lack of it, one may achieve better estimated shot and receiver's spectra for the sake of deconvolution. Analogously, extra terms could be used for gain compensation and bursts attenuation if a measure of the amplitude is used instead of spectra.

Acknowledgments

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References

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