

Application of Singular Spectrum Analysis for Ground Roll Attenuation

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Summary

A ground roll attenuation technique based on Singular Spectrum Analysis (SSA) is proposed. The technique is based on finding eigenimages that contain the main surface noise component within the ground roll cone. Examples of this filter application on synthetic and real 2D and 3D data are presented.

Introduction

Attenuation of surface waves such as ground roll or Rayleigh waves has always been a challenging problem in seismic data processing. When surface wave appears in the raw data, it may strongly degrade all of the following processing steps and the stack quality.

Ground roll features that can be used to discriminate this noise were described by many authors. This surface wave is characterized as a low-frequency (0-30Hz) wave with high amplitude and low velocity. Since it is a surface wave, it appears on shot gathers as a high amplitude noise visible in cone zones under the shots on shot gathers, or in hyperbola-delineated zones in case of 3D shot gathers. Ground roll often appears on shot gathers as a set of coherent linear events with apparent velocities around 400 m/s (Ferguson, 1994).

These properties of ground roll were used in various methods developed to eliminate it. Note that the simplest process to remove ground roll could be just application of band pass filter removing low frequencies, but such crude method would strongly affect all good data. Cary (2009) notes that traditional methods for filtering ground roll can be very effective, but they can have limited success because of irregular trace spacing and data aliasing, and applies a method utilizing singular value decomposition (SVD) to attenuate ground roll. It is also possible to use polarization filters or cascading approach to ground roll removal (De Meeserman, 2007).

Over the recent years, Singular Spectrum Analysis (SSA) or Cadzow has been successfully introduced in seismic data processing for filtering random noise. Nagarajappa (2012) successfully applied such technique (also known as Hankel matrix rank reduction filter) to attenuate coherent noise. Trickett introduced SSA technique on frequency slices where it showed good results. This technique is also AVO compliant.

In this work, application of SSA on frequency slices and decomposition to eigenimages is utilized to discriminate ground roll from the signal, and it is applied only in ground roll cones.

Theory and Method

Rank-reductions filters in application to seismic data are applied on frequency slices of input data. For each frequency slice, a Hankel matrix A is composed of complex Fourier coefficients c_i , $i = 1 \dots n$ as

$$A = \begin{bmatrix} c_1 & c_2 & \cdots & c_{n-m+1} \\ c_2 & c_3 & \cdots & c_{n-m+2} \\ \vdots & & \ddots & \vdots \\ c_m & c_{m+1} & \cdots & c_n \end{bmatrix}$$

(Trickett, 2003, 2009), and SVD is used to present matrix A as a sum of m eigenimages:

$$A = I_1 + I_2 + \dots I_m,$$

where each eigenimage $I_i = \sigma_i u_i v_i^H$, $\sigma_1 \geq \sigma_2 \geq \dots \geq \sigma_m$ is a singular value in SVD decomposition of $A = U \Sigma V^H$, u_i and v_i are column-vectors of unitary matrices U and V , and σ_i are diagonal elements of a diagonal matrix Σ .

Each eigenimage is a matrix of rank 1, and the strongest components of the signal are in the first eigenimages. At such representation, the rank reduction filtering is just leaving in the sum the first few r eigenimages which are supposed to be a part of a signal, and zeroing the eigenimages with higher numbers.

However, noise components may be presented by any eigenimages in this sum (Golyandina et al, 2007) and this property may help to discriminate the noise. In their case, visible footprint noise was represented by several eigenimages in the middle of this sum.

In case of ground roll, it has strong amplitude, and is represented by the first few eigenimages. Thus, to attenuate the ground roll noise, the first of these eigenimages (which also meet certain conditions) corresponding to ground roll need to be removed from the sum. This will turn a rank-reduction filter into a ground roll filter. All information about eigenimage magnitude is in its singular value, and it is used in this approach.

This filtering technique is applied only within the ground roll cone defined by minimum and maximum velocity of the surface noise, so there is no potential risk to harm any data other than in the noise cone. Such well known ground roll property as its linear event deep that is potentially useful for ground roll removal is not used in this method since it not always applicable on real datasets when ground roll may be aliased. However, we use ground roll velocity parameter to deliniate ground roll cone for filter application.

Figure 1 shows how decomposition to eigenimages may be utilized to discriminate strong ground roll. In this case first eigenimage (b) has the main part of the ground roll, while the sum of other eigenimages represents the signal (b). However, this is valid only for the ground roll cone zone.

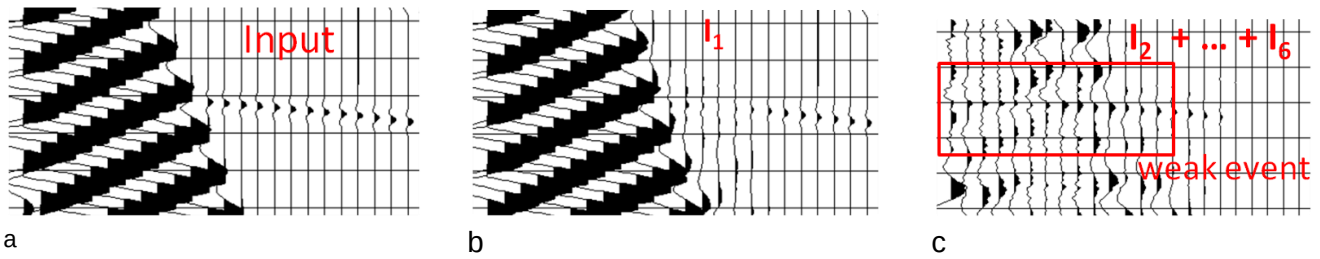


Figure 1. Illustration of Rank SSA filter principles. (a) Synthetic shot gather with ground roll. (b) First igenimage in the sum. (c) Sum of igenimages $l_2 + \dots + l_6$ shows weak event and little ground roll noise.

Synthetic Data Example

Figure 2 shows results of this filter application on synthetic data. The filter was applied on synthetic shot gathers with added random noise and strong synthetic ground roll. Note that added ground roll is aliased.

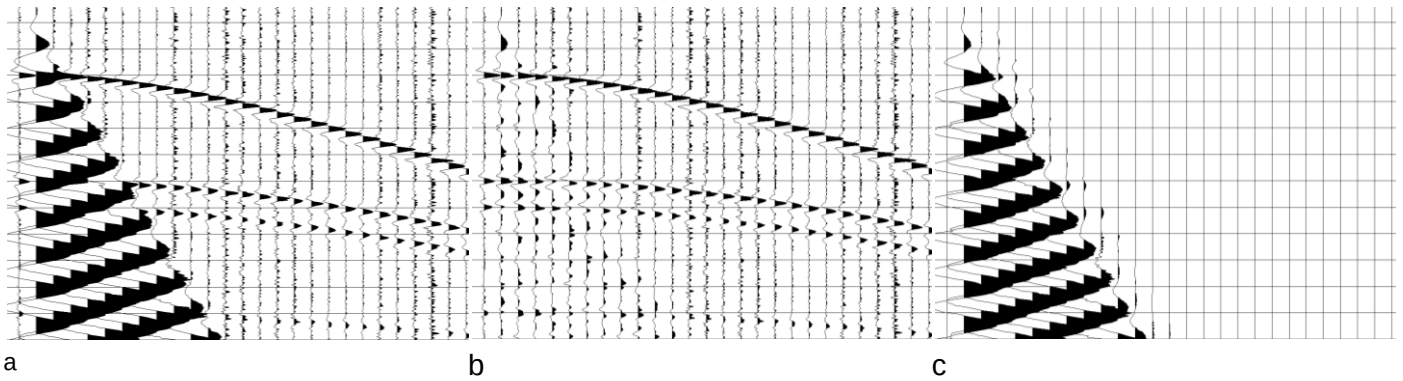


Figure 2. Illustration of Rank SSA filter application. (a) Synthetic shot gather with ground roll. (b) Rank SSA filter application. (c) Difference: Input - filter output.

Figure 3 shows that the spectra of input and filtered data are almost identical, and there is little or now harm to low-frequency data.

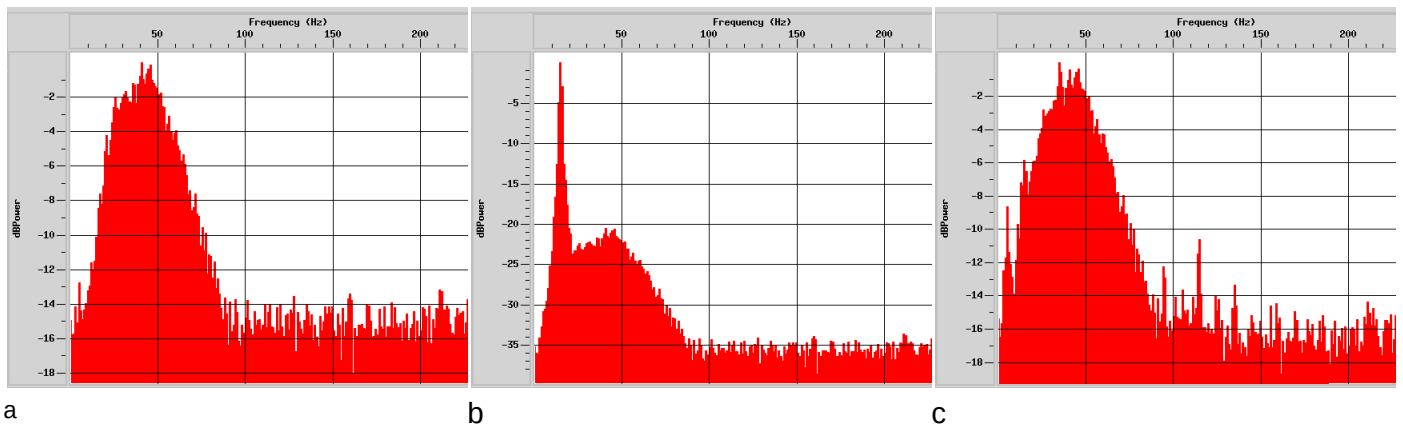


Figure 3. Comparison of input and output amplitude spectra. (a) Synthetic shot gather without ground roll. (b) Synthetic shot gather with added ground roll. (c) Difference: Input - filter output.

Real Data Examples

The following examples illustrate the results after application of Rank SSA ground roll filter on real 2D and 3D data.

Figure 3 shows the results after this technique was applied on 2D shot gather with strong ground roll noise. Despite the fact that some small remains of ground roll are visible after filter application, there is very little or no visible remaining signal on the difference plot.

Figure 4 shows the results after this method application was on 3D shot gathers with strong ground roll noise. Despite that some small remains of ground roll are visible after the filter application, there is very little or no remaining signal on the difference plot.

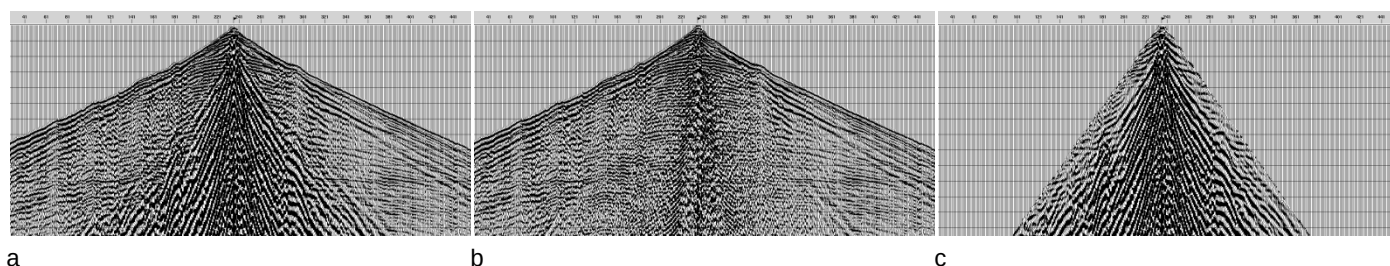


Figure 3. 2D data example. (a) Input shot gather with ground roll. (b) Rank SSA filter applied. (c) Difference plot: Input - filter output. Data courtesy of Geo-X.

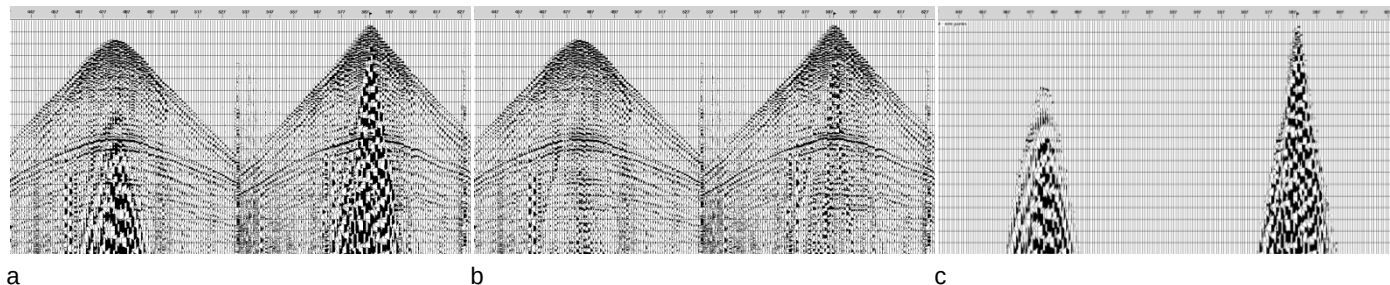


Figure 4. 3D data example. (a) Input shot gather with ground roll. (b) Rank SSA filter applied. (c) Difference plot: Input - filter output. Data courtesy of Geo-X.

Conclusions

The advantages this surface noise attenuation approach follow from the advantages of SSA / Cadzow filters which are known as amplitude preserving, and therefore it is AVO-compliant noise attenuation. This filter can attenuate aliased ground roll. It applies only within ground roll cone zone and can not make any harm to good data. This ground roll cone is simply defined by velocity parameter. This noise attenuation technique may have variable filter strength to avoid removal of the signal.

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References

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