Accurate Declipping Hybrid Algorithm for Ground Penetrating Radar Data

Akshay Gulati and R. J. Ferguson, University of Calgary
agulati@ucalgry.ca

Summary

This paper deals with the problem of clipped amplitudes in Ground Penetrating Radar (GPR) data. Commercially available software's uses the famous rubber band interpolation to undo clipping. Results obtain through this technique is unreliable, as it uses conventional spline interpolation. In this paper, we propose Hybrid method which uses combination of Kaiser Bessel Non uniform fast Fourier transform (NFFT) and Projection on Convex Set (POCS) to restore clippings. This algorithm is tested on synthetic and real data. To study the effectiveness of the technique, results obtained are compared with industry's standard rubber band interpolation.

Introduction

Ground Penetrating Radar (GPR) methods are based on the same principle as seismic reflection methods. It is now a widely accepted geophysical technique. It is a non intrusive technique for detecting buried objects. The basic principle behind the GPR method is the transmission of electromagnetic energy into the earth and subsequent reflection from the interfaces of differing dielectric permittivity. The GPR transmissions for the targeted subsurface form a synthetic aperture, whose impulse response is a spatially variant curve in the space-time domain. A common set up for GPR deploys a transmitter and receiver over a targeted zone.

Most commercial GPR software's consist of an editing tool known as 'desaturation' or 'declipping'. During acquisition of GPR, can become clipped as GPR receiver system saturates with strong ground coupling, and thus recorded trace is not representing the true peak amplitude of the returning signal. Generally adopted methodology under these circumstances is trace normalization. In trace normalization each trace is normalized to the peak amplitude usually ground wavelet. Due to this saturated traces will have their later arrivals artificially enhanced in comparison to the non saturated traces. Application of desaturation function attempts to correct for this effect by reconstructing the form of the ground wave pulse by rubber band interpolation or spline interpolation. Rubber band interpolation uses conventional spline interpolation for reconstructing the clipping. Drawback of this approach is that it uses a simple polynomial based approach without considering any property of signal.

Majority of regularization algorithm are designed for regular missing samples. In case of clipping gap size can be large therefore; it's a problem of irregular missing samples with a large gap. The problem of interpolation of irregularly sampled signals is more complex and less well developed. This paper uses newly proposed hybrid method for restoring clipping. In this Hybrid approach Projection on convex sets (Gerchberg and Saxton, 1972) along with Non uniform Fast Fourier kernel (Kunis and Potts, 2005) is used for solving the GPR clipping problem. This method will improve convergence rate and reduce the final reconstruction error. The main objective of this algorithm is to use oversampled gridding kernel, with POCS for reconstructing big gaps, which are clipping in present case.

Theory

POCS method is widely used for image reconstruction. The methodology involves finding a solution as an intersection property of sets rather than by minimization of a cost function. All image constraints are represented in a Hilbert space as a series of closed convex sets $\{C_i | i = 1, 2, \dots \dots m|\}$, then each projection is done iteratively on the intersection. In simple terms, this algorithm estimates the missing data in a Hilbert space from its known parameters.

If we have n properties of the original signal S, then each property define one of the convex sets C_i. Also, the original signal will be part of all sets as well as of the intersection of sets as in Figure 2.

$$S \in C = \cap_{i=1}^{n} C_i \qquad (1)$$

Equation 1 defines n sets for n properties of signal. The initial value of the signal is projected iteratively onto the intersection of all convex sets under the projection operator P. The optimal solution will be the point lying on the boundary of the intersection. Given the projection operator P_i onto C_i ,

$$S_{t+1} = P_n P_{n-1} \dots \dots P_1 S_t \qquad t = 1,2, \dots. \qquad (2)$$

Equation 2 shows an iterative procedure for the signal with its projection operators. In Equation 2 S converges to its limiting point of the intersection C in the Hilbert space H. The projection operator P_i will satisfy,

$$\|S - P_i S_i\| = min_{k \in C_i} \|S - K\| \qquad (3)$$

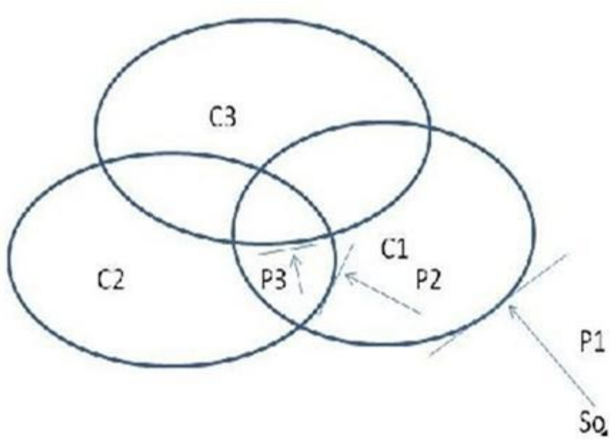

Fig 1 : The principle of POCS Method

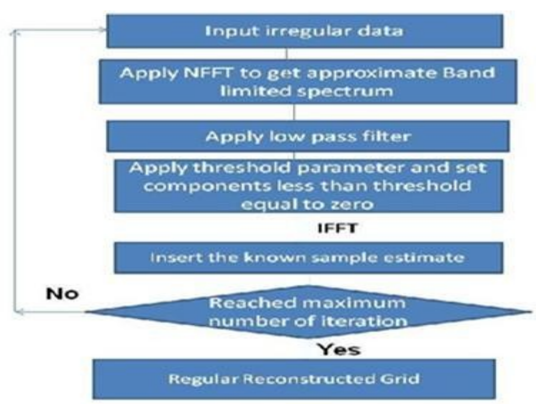

Figure 2: flow chart

The first step is to grid the data onto a regular grid using a gridding kernel. In this case the gridding kernel used is the kaiser Bessel kernel (Keiner et al., 2008), which convolves with the irregular data and distribute the samples onto a regular grid. This gridding kernel, which is used as non uniform fast Fourier transform (NFFT) kernel (Kunis and Potts, 2005),acts as simple FFT when the samples are already on a regular grid. The point to be stress that, if the gaps are small then the simple FFT kernel can be applied instead of NFFT.

POCS is iterative and typically projects consecutive solutions onto consecutive properties sets. Each iteration is followed by the NFFT kernel, which is the FFT when sampling is regular enough. A threshold is applied to the Fourier domain leaving components greater than the threshold as zero. During the first few iterations, sample points with high energy are restored. In each iteration, higher frequencies are made zero in the frequency domain. The threshold parameter enforces a cut off in amplitude which gives some amplitude to unknown values. After this, the values of known components are restored by replacing them with their true values. This will reconstruct the high frequency values. Samples will be reconstructed in each iteration (Figure 2). The whole process can be written in form of Equation 4.

$$S_k = S_{obs} + (I - S)\, F^{-1}\, T^k\, B(NFFT) S^{k-1} \qquad (4)$$

where, S_{obs} is an original data at kth iteration. S_{obs} will keep getting updated until it finally converges to a solution. NFFT and F^{-1} represents non uniform fast Fourier transform and inverse fast Fourier transform which operates on t. S is a sampling operator that identifies known and unknown values. T^k is threshold operator with elements.

$$T^k = \begin{cases} 0 & F_{k-1} \geq l_k \\ 1 & F_{k-1} < l_k \end{cases} \qquad (5)$$

Where, F_{k-1} denotes the Fourier domain representation of the reconstructed signal after the (k-1)th iteration. l represents the N dimensional threshold set $l = l_1, l_2, \ldots . l_N$ where $l_1 > l_2 > l_N$ and N denotes the maximum number of iterations.

Examples

Synthetic data

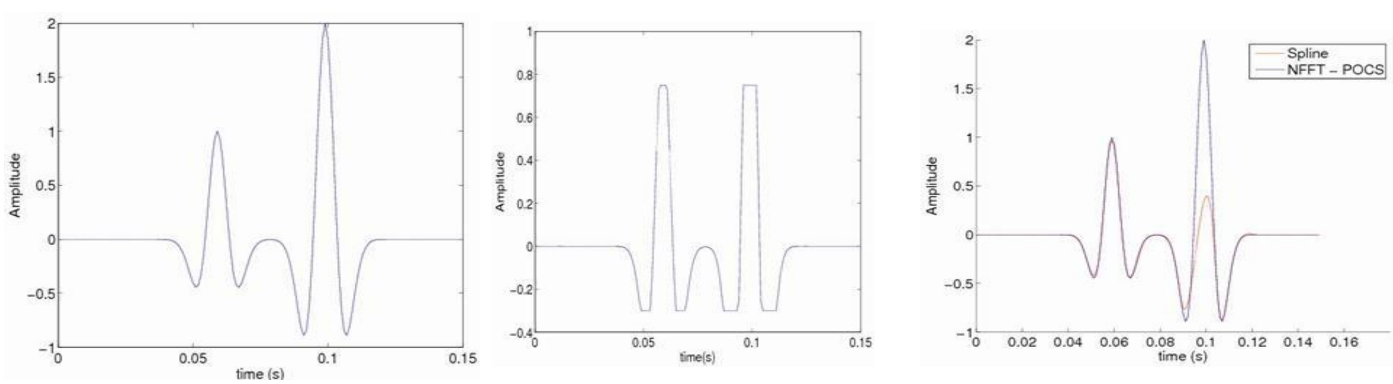

Fig3: a) Synthetic trace b) Clipped trace c) Reconstructed trace

Figure 3a is a synthetic trace made up of two ricker wavelets. To test the algorithm data is being clipped in Figure 3b. Followed by reconstruction using conventional spline and NFFT POCS. NFFT POCS is able to restore the clipping perfectly where as spline gave completely inaccurate reconstruction of second peak in Figure 3c.

Real data

Figure 5a shows the GPR data with a lake bottom reflection. The sampling rate for the acquired data set is 4ns. The bandwidth of data is 0-1250 MHz. Clipped amplitudes are clearly visible in Figure 6a along the top horizon. The data is compromised of 300 traces, each sampled for 750 ns. Sample traces from the data set can be seen in Figure 4a, where it is clearly evident that it is clipped with maximum amplitude of 32767 and minimum amplitude of -32768. Figure 4b shows the reconstructed traces using spline and Hybrid POCS. Clipped GPR data can be seen in Figure 5a. Figure 5b shows the reconstructed GPR section.

Horizons are successfully reconstructed, and the energy is continuous along the horizon. Figure 6c clearly shows the high amplitude difference between reconstructed section using spline and NFFT –POCS.

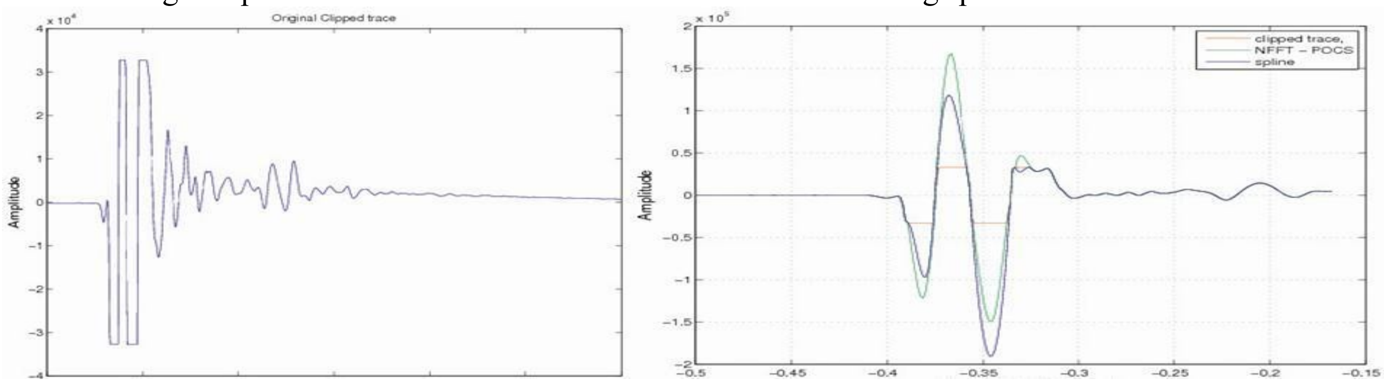

Fig4: **a) Original trace** **b) Reconstructed trace**

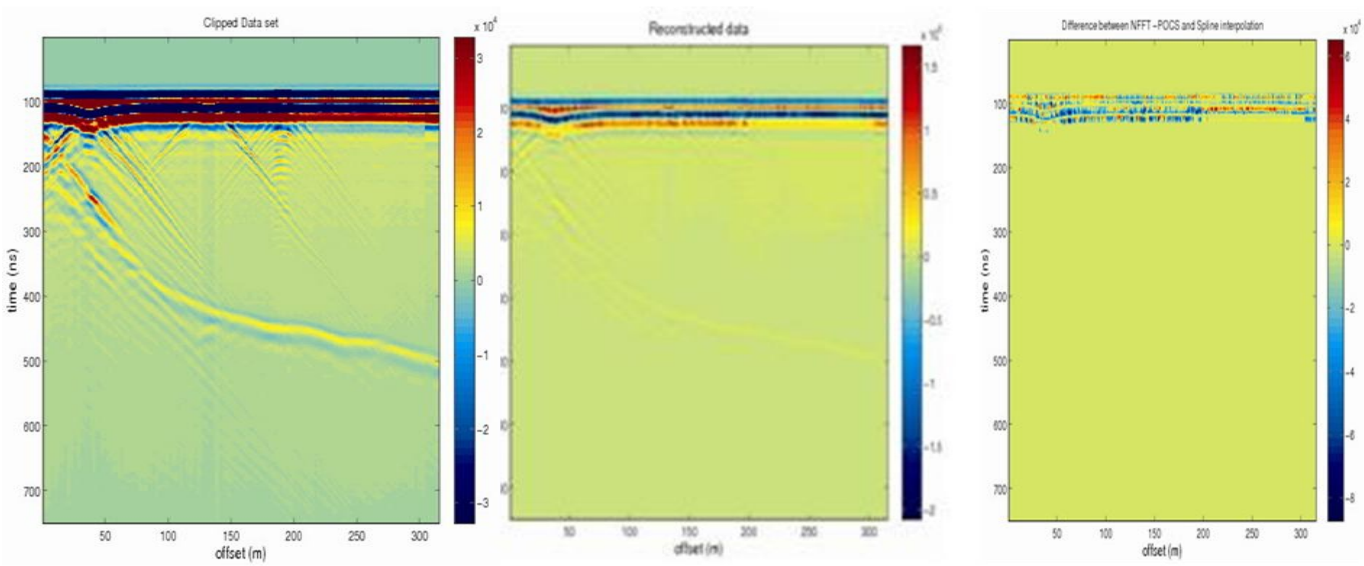

Fig 5: **a) Original Clipped GPR data** **b) Reconstructed data using Hybrid method** **c) Residual between NFFT-POCS and spline**

Conclusion

In this paper, an algorithm for clipped amplitude restoration using hybrid POCS has been presented and tested. It is able to completely restore the clipped amplitudes of GPR data. Two different methods for estimating the clipping have been tested. The first one is conventional method of spline interpolation, which is largely adopted in GPR industry. The second is hybrid POCS, which uses *a priori* information from the signal to recover clipped amplitudes. A comparative study is done, which showed that Hybrid POCS is better than conventional spline interpolation. Hybrid POCS is better technique due to improved lateral continuity of the energy across the horizons in reconstructed data

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