Structure aware noise reduction of multi-channel ground penetrating radar data using Principal Component Analysis

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Abstract
Multi-channel ground penetrating radar (GPR) may contain interference and decoupling noise. Principal Components Analysis (PCA) is applied to adjacent GPR data channels to reduce noise. Structure aware image fusion only replaces areas of isolated noise.

Keywords
ground penetrating radar; noise reduction; Principal Component Analysis; structure aware image fusion

Introduction

Ground penetrating radar (GPR) data can be adversely influenced by sources of radio frequency (RF) noise or when a ground coupled antenna loses coupling with the ground surface. This can be a particular issue for multi-channel antenna when acquiring data over uneven ground surfaces where, due to the ~2 m width of the array, it may become levered off the ground as it passes over surface irregularities. The noise is often most prominent in the outer channels of the array as these are more likely to be lifted away from ground surface and may also have reduced shielding from RF noise compared to the inboard antenna elements. While this may be largely cosmetic, suppressing the influence of this noise within densely sampled data sets can improve both the presentation and interpretation of time slices derived from the data.

Principal Components Analysis (PCA) has been demonstrated to be effective for the suppression of pixels attributed to noise when no correlation occurs between adjacent GPR time slices created from a single channel data set (Linford 2004). Multi-channel data provides a greater cross-line sample density allowing PCA analysis for noise suppression between both adjacent vertical profiles across the array and horizontal slices through the swath. The greater sample density allows for a more confident identification of random noise and will not, necessarily, be influenced by the positioning errors or the vertical integration of the data into aggregated 'thick' time slices. In addition, structure aware image fusion (Li et al. 2018) between the original and PCA noise suppressed data has been applied to preserve areas of detail where no excessive noise has been identified.

Methods

Data was collected with a 3d-Radar (Kontur) MkIV GeoScope Continuous Wave Step Frequency (CWSF) GPR system with a 20 channel DXG1820 vehicle-towed, ground-coupled antenna array at a 0.075 m by 0.075 m sample interval. PCA analysis is performed between adjacent profiles from the individual channels across the array, replacing the central profile with the maximum correlation profile defined by the highest eigen-value (Gonzalez and Wintz 1987, pp. 122-125). This should preserve the greatest degree of correlation between the adjacent profiles and, hopefully, suppress random noise present only in a single channel.

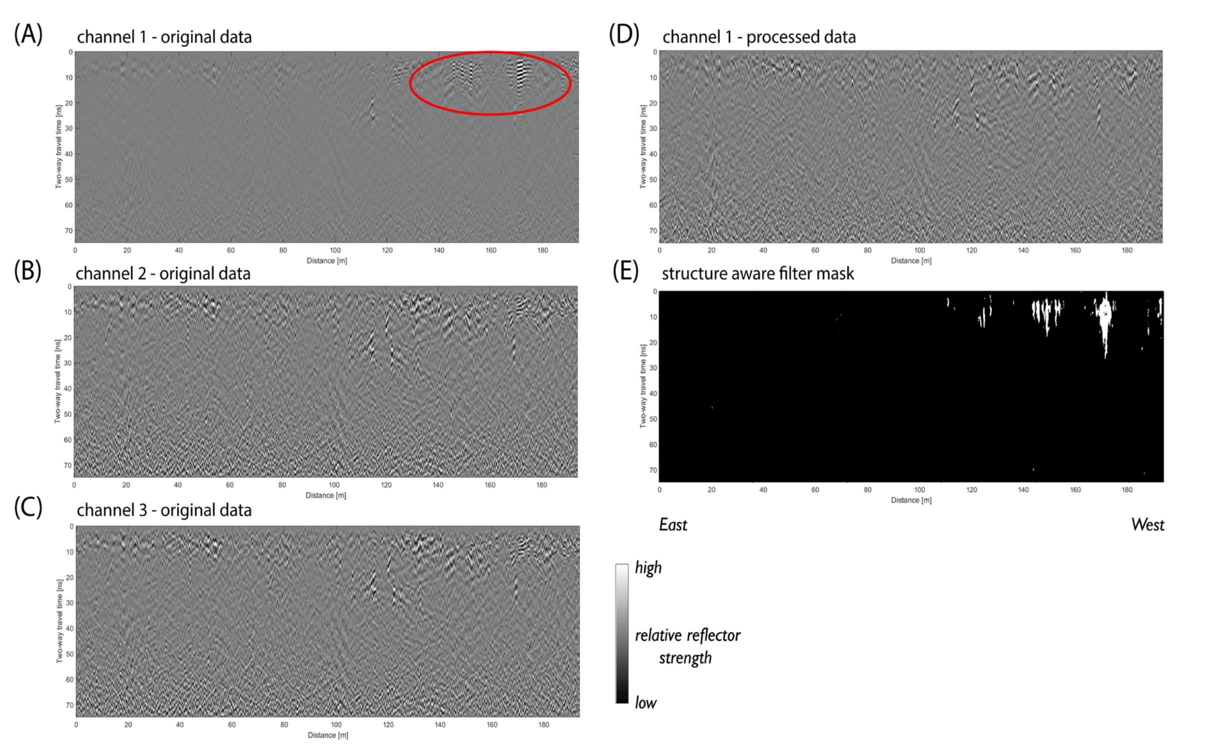

Fig. 1: GPR profiles from the first three adjacent channels from an array based antenna (A), (B) and (C). The outer most channel 1 shown in (A) contains acquisition noise due to the uneven nature of the ground surface between approximately 120 m to 180 m (red circle). The noise in channel 1 has been successfully suppressed through the application of PCA analysis performed between adjacent channels (D) in regions identified by a structure aware image fusion mask (E).

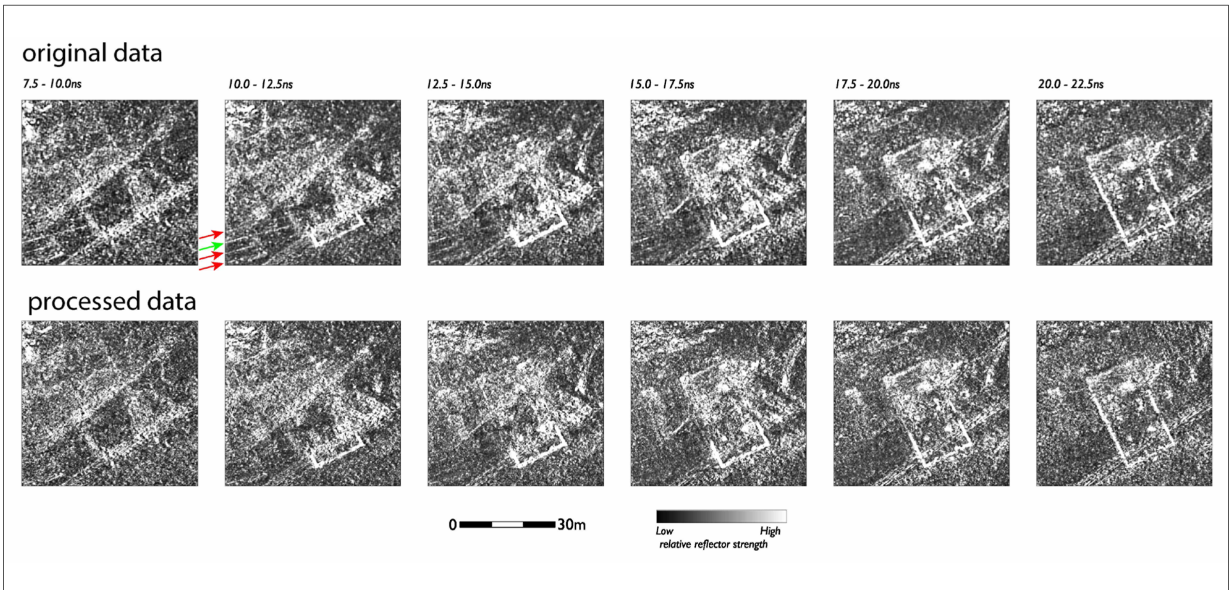

Fig. 2: Extracted amplitude time slices from the GPR survey at Sibton Abbey, Suffolk. The upper row shows the original data containing the profiles shown in Figure 1 (green arrow) together with adjacent instrument swaths showing measurement noise in the outer channel (red arrows). The lower row shows processed data where the measurement noise has been suppressed.

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Data from the central profile and maximum correlation profile are subsequently combined using a structure aware image fusion algorithm (Li et al. 2018). This method has been modified to recover small-scale details of the maximum correlation profile in the neighborhood of large-scale noise structures of the input profile, only applying image fusion to the areas affected by noise. A structure-preserving filter is determined by a 2D convolution of the input profile with an edge detecting structural element h = [1,-1] in both a horizontal and vertical orientation. Subtracting a convolved input profile containing noise from the convolved maximum correlation profile of adjacent channels creates a mask to isolate the image fusion to the localized noise degraded areas (Fig. 1, (E)).

Results

Figure 1 shows the GPR profiles from the first 3 channels from a multi-channel array where the first channel contains isolated noise (Fig. 1, (A), (B) and (C)), between approximately 120 m and 180 m, due to the uneven nature of the site terrain. The area of high-amplitude noise has been isolated by the structure preserving filter (Fig. 1, (E)) allowing the noise to be successfully suppressed following image fusion with the PCA maximum correlation profile (Fig. 1, (D)). In this case the noise occurred in a number of adjacent instrument swaths and is visible as distracting linear artefacts in time slices created from the data (Fig. 2). Processing all of the instrument swaths with the method described above has successfully suppressed the linear artefacts within the time slices with minimal adverse impact on more significant anomalies.

Conclusion

The application of PCA based analysis can be successfully used to suppress isolated noise through the analysis of both adjacent GPR profiles and horizontal time slices. This works particularly well with multi-channel array based GPR antennas where the sample density within each instrument swath allows for the successful suppression of noise in the outer most channels. Structure aware image fusion helps preserve original data in the profile where it appears that no noise has been detected.

References

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