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Application of Multiresolution Analysis in Removing Ground-penetrating Radar Noise

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Summary

The wavelet method has already been applied extensively to image processing and potential-field data, but rarely to GPR data. Multiresolution wavelet analysis (MRA), one of the most effective wavelet techniques used in image processing, allows an image to be described in terms of a rough shape, plus details in a broad range which may be useful for filtering processes. The 2D GPR section is similar to an image in all aspects if each data point of the GPR section is considered to be an image pixel in general. By this method, the MRA provides an efficient filtering basis. A synthetic model study followed by a field example is presented to demonstrate the feasibility of this technique in the filtering process for enhancing the S/N ratio of the GPR data. We paid special attention to the data with serious ringing or scattering noise sources, where this method proved to be very useful.

Introduction

Due to the kinematic similarities between electromagnetic (radar) and seismic wave propagation, GPR data are usually processed with a technique similar to the technique used in seismic data. Although a multi-channel GPR system is currently available, the most common GPR survey still acquires data in single fold for the purposes of prompt field operation and low cost. Without the stacking procedures used in seismic CMP processing, the S/N ratio enhancement of GPR records can be achieved only in the subsequent data processing. In this paper, we propose an MRA technique based essentially in wavelet analysis for noise suppression. The MRA is a well established mathematical tool in wavelet analysis for image compression (Stollnitz et al., 1995) and de-noising (Mohideen et al., 2008), and has been introduced to the geophysical data processing area in recent years with limited published literature (Matos and Osorio, 2002; Nuzzo and Quarta, 2004). Most of the related studies were applying the wavelet transform to suppress noise in a time-frequency sense (Deighan and Watts, 1997; Leblanc et al., 1998; Miao and Cheadle, 1998).

The operation of MRA is to recursively calculate the average and difference of the pixel values for each row (or column) pairwise until an overall average (approximation coefficient) is obtained, and the differencing values for each step are details (detail coefficients). By this way, the MRA provides an efficient filtering basis to suppress events of specific scales locally but leave the rest of the data unaffected in general. In this study, we show the application of this technique to enhance the S/N ratio of GPR sections.

Theory and Methods

There are two ways we can perform the MRA, i.e., the standard and nonstandard decompositions (Stollnitz et al., 1995). The standard decomposition is to first apply the one-dimensional wavelet transform to each row of pixel values. The process yields an average and details for each row. We then apply the one-dimensional transform to each column of these transformed rows as if they were themselves an image. The final pixels of the transformed image are all detail coefficients except for a single overall average coefficient at the first row, first column.

The nonstandard decomposition is an interchange between operations on rows and columns. First, we perform one step of horizontal pairwise averaging (low-pass filtering, noted by L) and differencing (high-pass filtering, noted by H) in each row of the image pixels, followed by applying vertical pairwise averaging and differencing to each column of the previous horizontally transformed pixels. The subsequent process is to recursively perform the transform only on the quadrant containing averages in both directions (Fig. 1).

Both of these decompositions have their advantages, depending upon the application. For the purpose of 2D multiresolution filtering, we prefer the nonstandard decomposition because at each level of decomposition, it results in a low-resolution approximation (LL quadrant in Fig. 1a) and three types of different resolution details, *i.e.*, horizontal (LH quadrant in Fig. 1a), vertical (HL quadrant in Fig. 1a), and diagonal (HH quadrant in Fig. 1a), which would be easier for us to identify the signal and noise components. Moreover, the nonstandard decomposition requires fewer operations and has square supports for each basis function. Fig. 1b illustrates the hierarchical structure of nonstandard 2D decomposition.

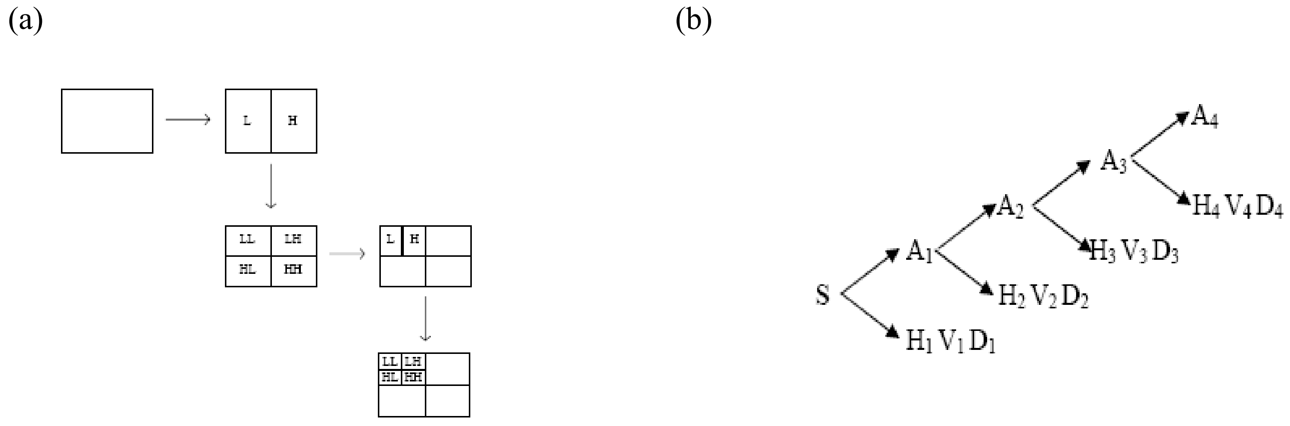

Figure 1: (a) Nonstandard decomposition of 2D discrete wavelet transform. (b) Filter bank of nonstandard 2D decomposition where S represents the original image, A_n the approximation coefficient of n^{th} level. H_n , V_n , and D_n are the horizontal, vertical, and diagonal detail coefficients of n^{th} level, respectively.

Examples

Synthetic model study

In order to carry out a systematic investigation of using MRA in the GPR data filtering, a controlled synthetic model study is performed to provide an empirical filter bank for use in reconstructing the signal. Fig. 2a is a noise free 2D synthetic GPR model section with four horizontal reflection events. To test the effects of the 2D MRA filtering, we then added white Gaussian noise (S/N = 1) to the model (Fig. 2b). The signal events of the model are nearly invisible once the noise was added. The reconstructed image after 2D MRA filtering is shown in Fig. 2c, in which the components H_1, D_1, V_1, H_2, D_2, V_2, H_3, V_3, D_3, D_4, and V_4 containing mostly white noise were zeroed off to obtain a global filtering.

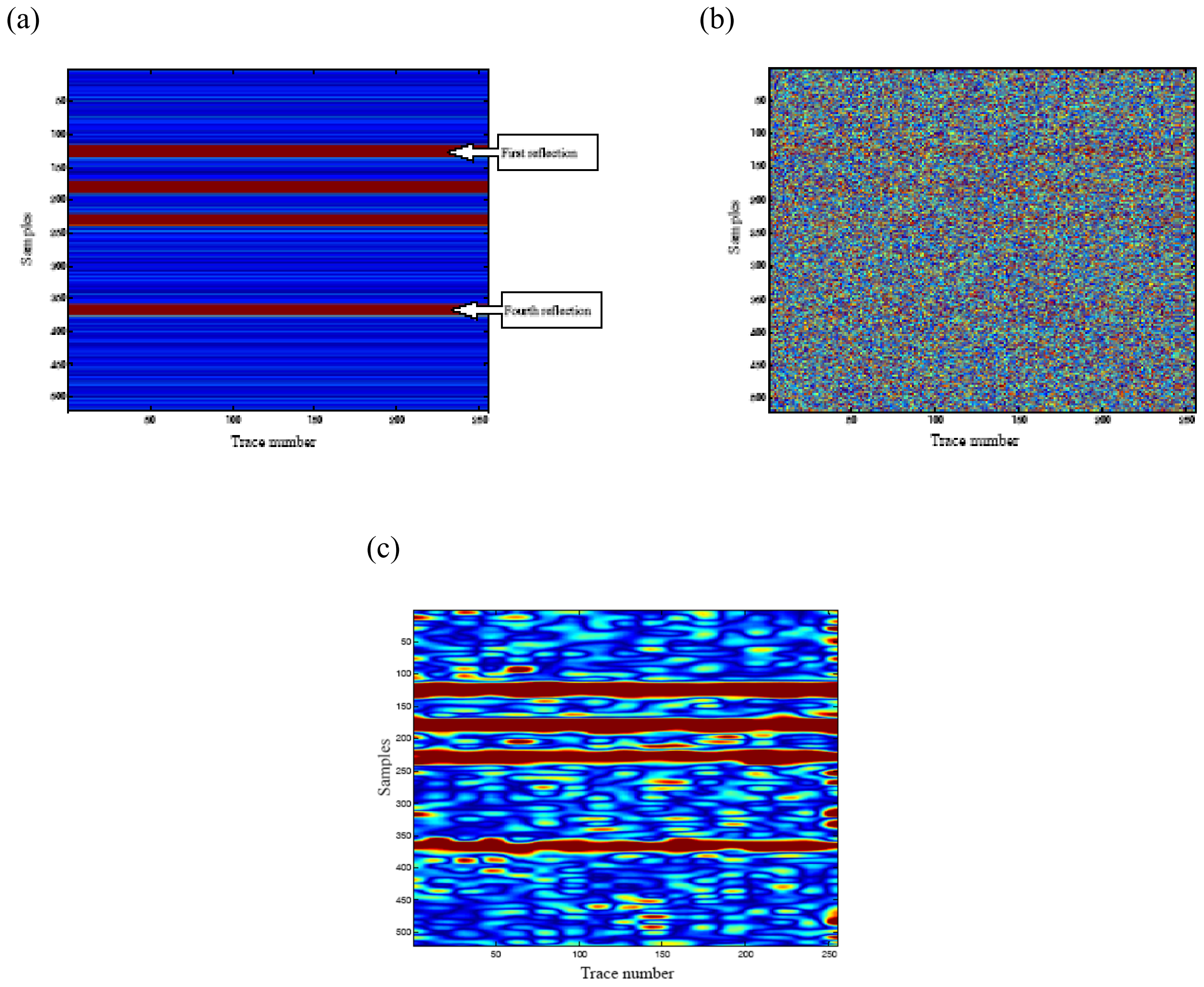

Figure 2: (a) 2D GPR reflection model without noise. (b) Noise added model. (c) MRA processed result.

Field example—Removal of ringing noise

Applying the technique developed in the model study, we take a real GPR section recorded at a relic site at the Taichung Municipal Park in central Taiwan. The data show a strong local ringing section at distance between 24.3 m and 25.2 m (Fig. 3a), which may be caused by a metallic lid of an abandoned cistern near the earth surface. The first stage MRA results of this section indicate that the detail components of H_1, V_1, D_1, H_2, V_2, D_2 and D_3 contain strong ringing noise, and should be removed. H_3 was not removed in the beginning because it contained both reflection signal and ringing noise. To retrieve the signal in component H_3, we treated it as an original image and applied the MRA procedure again to that single component. The result of decomposing H_3 indicates that the components of H_{23}, D_{23}, V_{23}, H_{33} contain mostly ringing noise (H_{23} denotes the second level horizontal detail coefficient of H_3, and so forth). The components beyond level 3 of the original image decomposing were trivial; therefore no further action was taken. Fig. 3c is the filtered results of removing original detail coefficients H_1, V_1, D_1, H_2, V_2, D_2, D_3, H_{23}, D_{23}, V_{23}, and H_{33}.

Conclusions

We have demonstrated the MRA technique in primary and secondary decomposition as well as how to use them for suppressing random noise and removing ringing noise with less distortion of GPR signals. Before a more robust algorithm is developed, acquiring reasonable knowledge of the noise pattern to the data would help the investigator to resolve the noise components for signal enhancement.

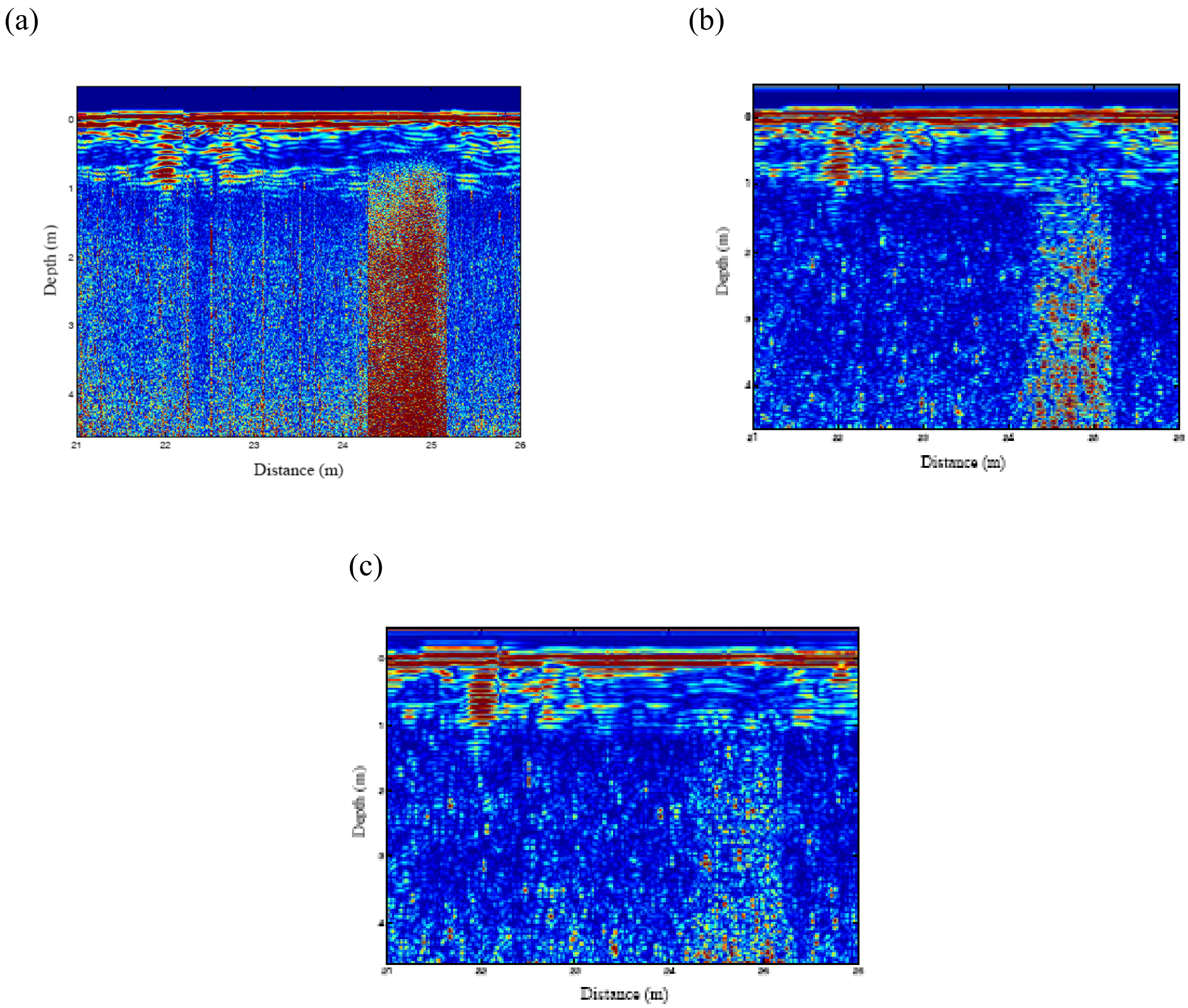

Figure 3: (a) Original field section with local ringing noise. (b) MRA filtered result by zeroing off components H_1, V_1, D_1, H_2, V_2, D_2, and D3. (c) Further suppression of ringing noise by removing sublevel components of H_{23}, D_{23}, and V_{23} in (b).

Acknowledgements

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