Clutter Reduction Filtering in Borehole Radar Signals

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Abstract

In monostatic borehole radar data, target signals tend to be obscured by borehole and cable-related clutters. To reduce clutter effects, three filtering techniques such as neighbouring difference, average removal, eigenimage removal are applied to real measurement data of our monostatic borehole radar. The potential of the eigenimage filtering technique is investigated.

Keywords : Clutter Filtering Borehole Radar

1. Introduction

Borehole radar system has been often used for detection of underground anomalies in deep subsurface zone [1]. Generally, unwanted components related to system, cable and borehole clutters are strong and target signals is weak [2]. Thus, target detectability of borehole radars is limited by clutters. In single-hole mode operations of borehole radar, since borehole and cable-related clutters have large effects on the scan data, target signals are severely blurred and difficult to detect. Switch noises of a transceiver in a borehole radar and borehole reflections along radial direction are displayed as vertical lines of scan data. Cable-related borehole effects become diagonal line patterns in scan data.

In this literature, a monostatic borehole radar is operated at a test site in Korea and three clutter reduction techniques such as neighbouring difference, average removal, eigenimage removal filtering are applied to scan data. We show that the eigenimage filtering technique may be a promising technique of clutter reduction.

2. Clutter Reduction Techniques

As a simple approach, the effects of clutters may be assumed as globally constant distribution and target signal is locally distributed in scan data, some signal processing can be applicable to clutter reduction of ground-penetrating radars [3]. In this case, neighbouring difference (ND) and average filtering (AF) are well suited to planar clutter reduction. Firstly, neighbouring difference between the nth and the $(n-1)$ th A-scans is given by

$$A_{n,ND}(t) = A_n(t) - A_{n-1}(t) \cdot \quad (1)$$

Equation (1) is an approximated implementation of the spatial derivative of scan data along the depth line. Secondly, average filtering is achieved by subtracting from each A-scan an averaged value of A-scans over the area of interest as

$$A_{n,AF}(t) = A_n(t) - \frac{1}{N}\sum_{n=1}^{N} A_n(t), \quad (2)$$

where N is total number of A-scans.

In digital image and seismic signal processing, the singular value decomposition (SVD) has been often used to separate signal and noise [4]. According to the SVD, the raw data matrix B of B-scan, which is a set of A-scans along the depth, is decomposed to

$$B = \sum_{i=1}^{r} \sigma_i u_i v_i^T \quad (3)$$

where r is the rank of B. u_i and v_i are the eigenvetors of BB^T and $B^T B$, respectively. σ_i is the ith singular value. The superscript T is the transpose operator of vector. $\sigma_i u_i v_i^T$ is called as the ith eigenimage with the weighting factor σ_i. Since low-rank eigenimages have large singular value, these are highly coherent components. In scan data of a monostatic borehole radar, since the level of clutters are larger than that of target signals, low-rank eigenimages may be approximated to clutter contributions. Thus, the subtraction of the low-rank eigenimages from raw data may be written as

$$B_{LRR} = B - \sum_{i=1}^{p} \sigma_i u_i v_i^T = \sum_{i=p+1}^{r} \sigma_i u_i v_i^T \quad (4)$$

where $p \geq 1$ is the rank of the removal filtering.

3. Results

The filtering techniques are tested on real measurement data of our monostatic borehole radar. Scan data are collected at a test site in Korea. In this site, an air-filled tunnel is located at the depth of 73 m from the ground surface. A borehole with 20 cm diameter was drilled up to 120 m depth. Our monostatic borehole radar is operated in this borehole.

A set of raw data is displayed as shown in Fig. 1(a). Along vertical and diagonal directions, clutter signals are widely distributed. In this image, the tunnel signals are invisible. As shown in Fig.

1(b), the neighbouring difference technique is applied to Fig. 1(a). Although vertical clutters are sufficiently removed, diagonal clutters are still dominant. Thus, the detection of tunnel signals may be difficult. Fig. 1(c) is the result of average removal filtering in Fig. 1(a). A hyperbola of the tunnel can be seen dimly. More reduction of vertical and diagonal clutters is required.

Removal filtering of low-rank eigenimages is applied to Fig. 1(a). As a function of the filtering rank p, the results of the low-rank eigenimage filtering are shown in Fig. 2. In case of $p=1$, the low-rank filtering in Fig. 2(a) is similar to average removal in Fig. 1(c). As the filtering rank increases, clutters are reduced little by little, as shown in Fig. 2. Hyperbolic patterns of the tunnel at the depth 73 m remain unclear because of diagonal clutters. Thus, to enhance signal-to-clutter ratio, diagonal clutters should be sufficiently reduced. Fig. 2 shows that diagonal clutters have approximately same inclination. This feature may be a clue to reduce diagonal clutters. In the presentation, we will provide the results of the sufficient reduction of diagonal as well as vertical clutters.

4. Conclusion

Three clutter reduction techniques were tested to scan data of our monostatic borehole radar. Vertical clutters are sufficiently reduced by employing the neighbouring difference and the average removal techniques. But diagonal clutters still remains. Since clutter contributions as a function of the filtering rank may be decomposed to eigenimages, the eigenimage filtering of scan data may be applicable to adaptive filtering of diagonal as well as vertical clutters. In the presentation, a feasibility of adaptive clutter filtering will be provided by employing the eigenimage filtering and additional processing.

References

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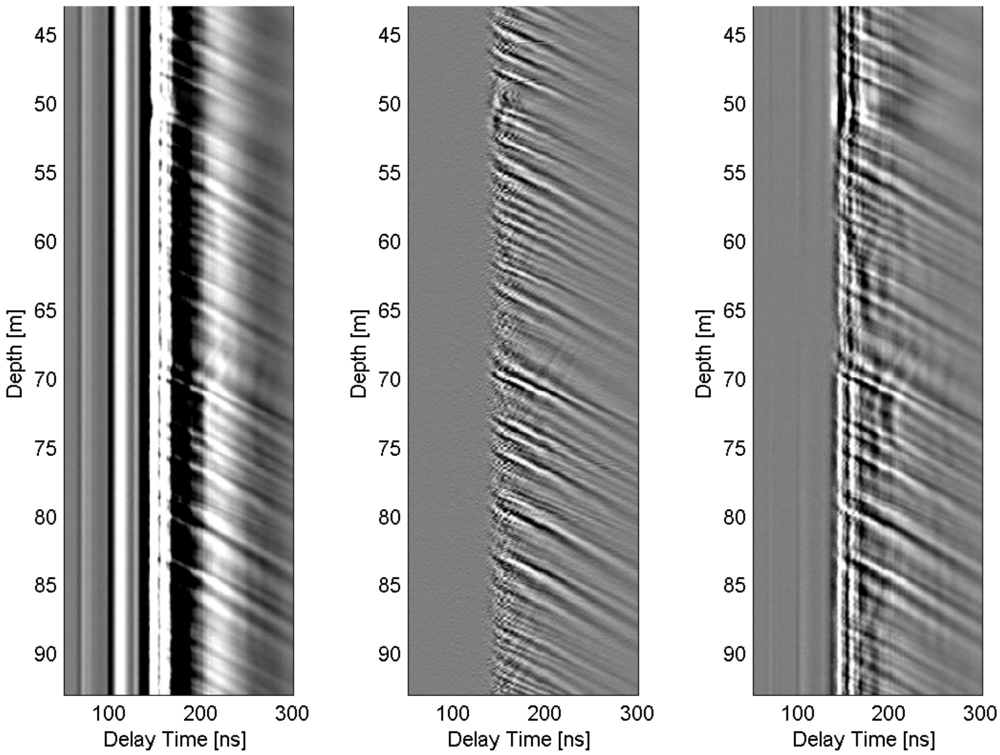
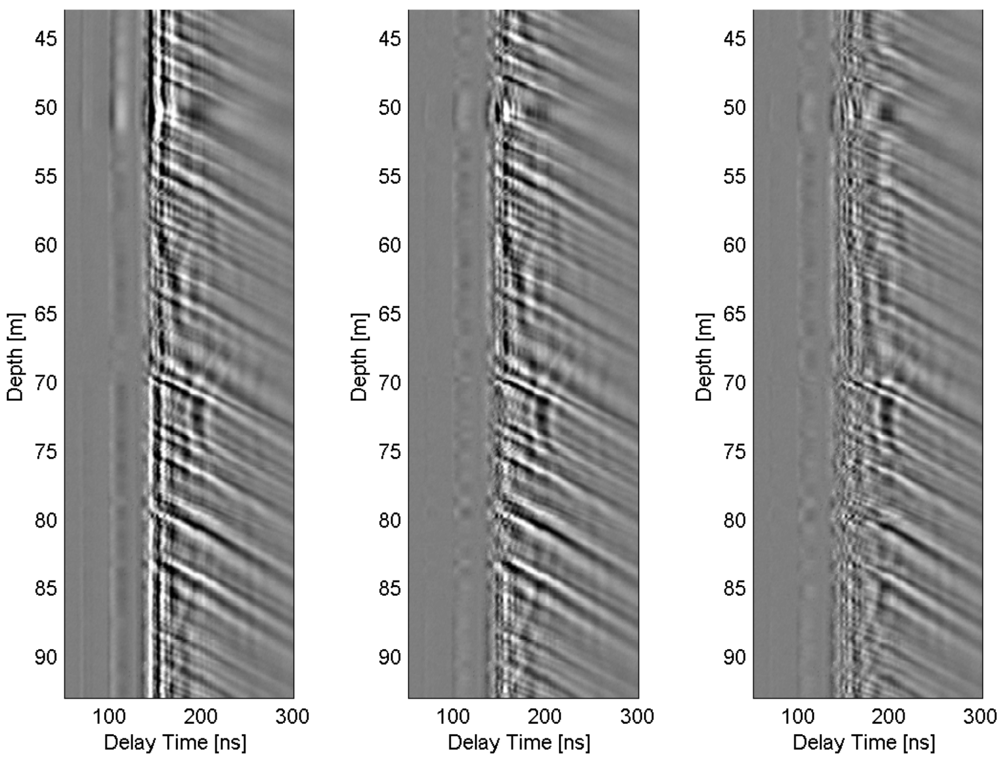


(a) (b) (c)

Figure 1: (a) Raw Data, (b) Neighbouring Difference and (c) Average removal.



(a) (b) (c)

Figure 2: Low-rank Eigenimage Filtering with the Rank of (a) $p = 1$, (a) $p = 2$ and (c) $p = 4$.