Clutter Removal of GPR Data using Complex Natural Resonance Extraction

John J. Pantoja[1,2] , Eder F. Ruiz[2], Felix Vega[1,2], Daniel Chaparro-Arce[2], and Chaouki Kasmi[1]

[1]Directed Energy Research Center
Technology Innovation Institute
Abu Dhabi, United Arab Emirates
john.pantoja@tii.ae

[2]Departamento de Ingeniería Eléctrica y Electrónica
Universidad Nacional de Colombia - Sede Bogotá
Bogotá, Colombia

Abstract— **In this paper we present a technique to remove clutter components on B-scans of ground penetrating radar. The technique is based on the complex resonance expansion of the signal, and the removal of poles associated with the clutter. For illustration technique is demonstrated on a buried metal sheet. Results show that the object is clearly highlighted and the clutter reduced in the B-Scan after applying the proposed technique.**

I. Introduction

Despite the efforts for clearance of antipersonnel landmines and improvised explosive devices, they remain a significant cause of causalities in several countries around the world [1]. Humanitarian demining using ground penetrating radar has increased due to its ability to detect low-metallic-content objects such as dielectric landmines and improvised explosive devices (IEDs) [2]–[4].

Nevertheless, identification of buried objects using GPR is challenging when the survey is performed on lossy soils, since discriminants are susceptible to the frequency dependence of the soil properties [5]. In that case, the measured pulse is strongly disturbed by the soil dispersion and attenuation [5], [6]. On the other hand, reflected signals produced by clutter can produce false alarms in demining operations [3]. Consequently, human supervision and data analysis based on in-situ soil properties are required to optimize the identification process.

The technique presented in this paper looks to improve the quality of the B-scans by automatically removing known, undesired responses in the backscattered signal produced by the clutter.

II. B-Scan Clutter Removal

A. Convolutional Model

Consider the following convolutional model, which assumes a linear time-invariant process [3].

$$y(t) = x(t) \otimes \big(h_t(t) + h_c(t)\big), \quad (1)$$

where $y(t)$ is the measured signal, $x(t)$ is the input signal, h_t is the target impulse response, and h_c is the clutter impulse response.

Rewriting (1), one obtains

$$y(t) = x(t) \otimes h_t(t) + x(t) \otimes h_c(t), \quad (2)$$

Representing both addends in (2) by their singularity expansion [7], yields to:

$$y(t) = \sum_{i=1}^{N} R_{t,i} e^{s_{t,i} t} + \sum_{i=1}^{M} R_{c,i} e^{s_{c,i} t}, \quad (3)$$

where $R_{t,i}$ and $s_{t,i}$ are, respectively, the residual and poles of the target response and $R_{c,i}$ and $s_{c,i}$, respectively, the residual and poles of the clutter response.

In a B-scan, one signal is received for each position in the longitudinal sweep. In that case, the received signals depend on the discrete temporal variable k, the time step Δt, and the longitudinal position j.

$$y(k,j) = \sum_{i=1}^{N} R_{t,i,j} e^{s_{t,i,j} k\Delta t} + \sum_{i=1}^{M} R_{c,i,j} e^{s_{c,i,j} k\Delta t}, \quad (4)$$

For the positions in which there is no contribution from target, the measured signal corresponds to the clutter component

$$y_c(k,j) = \sum_{i=1}^{M} R_{c,i,j} e^{s_{c,i,j} k\Delta t}. \quad (5)$$

B. Clutter Removal Technique

Equation (5) indicates that the clutter response can be represented by means of a set of M poles. Here it is assumed that y_c includes the effect of the direct wave signal coupled from the transmitter to the receiver, ground reflection and reflections coming from subsurface layers, and soil inhomogeneity due to buried objects such as rocks, roots, waste, or other clutter in the soil.

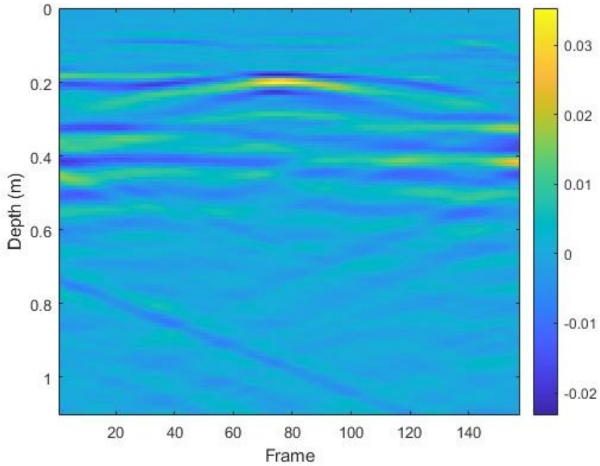

Fig. 1. B-Scan of a metal sheet under concrete slabs using background removal.

If the medium is statistically homogeneous along the observation area between j_1 and j_2, it is possible to define an average clutter response as

$$\bar{y_c}(k) = \frac{1}{j_2-j_1}\sum_{j=j_1}^{j_2} y_c(k,j), \tag{6}$$

which is represented by the average clutter poles and residuals as

$$\bar{y_c}(k) = \sum_{i=1}^{M} R_{ac,i} e^{s_{ac,i}}. \tag{7}$$

Clutter poles can be removed using elliptical windows on the pole's complex plane with the center located at the average clutter poles $s_{ac,i}$. In this case, the obtained signal has the contribution from the target response, poles located inside the elliptical window multiplied by the weighting factor W_i, and poles that are located outside the elliptical window, as shown in (8).

$$y_{pe}(k,j) = \sum_{i=1}^{N} R_{t,i,j} e^{s_{t,i,j}} + \sum_{i=1}^{P_j} W_i R_{c,i,j} e^{s_{c,i,j} k\Delta t} + \sum_{i=P_j}^{M} R_{c,i,j} e^{s_{c,i,j} k\Delta t}. \tag{8}$$

III. RESULTS AND DISCUSSION

The clutter removal technique was applied to a B-Scan obtained from a sweep over metal sheet placed under concrete slabs. A GPR operating between 300 MHz and 3 GHz was used. A longitudinal sweep was made with an XY positioning system which scans over 120 cm with a total of 160 frames.

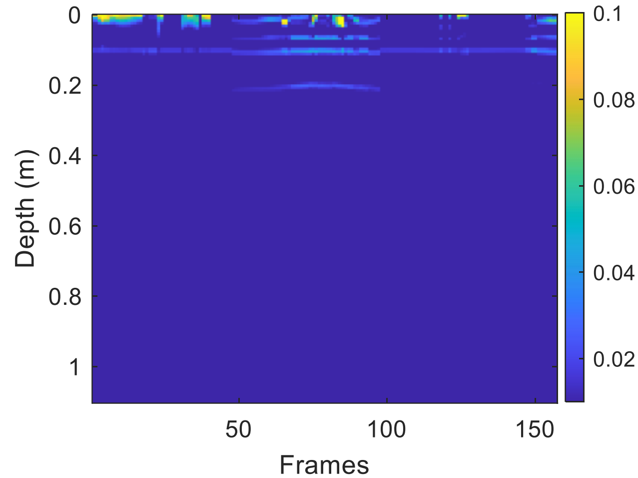

Fig. 2. B-Scan of a metal plate under concrete slabs after applying elliptical-windowing clutter-pole removal.

Each position was expanded using 16 poles and the pole extraction technique was used to remove the clutter. Figure 1 shows a B-scan applying background removal, a well-known clutter removal technique [3]. Figure 2 shows the obtained B-scan applying the elliptical-window clutter-removal technique. As shown in Fig. 2, the position of the object is clearly highlighted in the B-scan and the clutter response is reduced. It is remarkable that the interface between air and the concrete slabs is also clearly visible as a horizontal line in the radargram.

Results shows that the use of pole extraction technique allows one to select and eliminate undesired poles in a B-scan. Particularly, it was shown that clutter poles can be removed from a B-scan if they can be identified in the measured data set. Work is in progress to assess the application of this technique on buried low-metallic-content objects on natural soils.

REFERENCES

[1] ICBL-CMC (International Campaign to Ban Landmines), "Landmine Monitor 2019," 2019. [Online]. Available: www.the-monitor.org.

[2] J. J. Pantoja, N. Pena, F. Rachidi, F. Vega, and F. Roman, "Characterization, modeling, and statistical analysis of the electromagnetic response of inert improvised explosive Devices," IEEE Trans. Electromagn. Compat., vol. 56, no. 2, 2014, doi: 10.1109/TEMC.2013.2284964.

[3] S. Gutierrez, F. Vega, F. A. González, C. Baer, and J. Sachs, "Application of Polarimetric Features and Support Vector Machines for Classification of Improvised Explosive Devices," IEEE Antennas Wirel. Propag. Lett., vol. 18, no. 11, pp. 2282–2286, 2019, doi: 10.1109/LAWP.2019.2934691.

[4] M. Sato, K. Kikuta, and R. B. Miller, "Evaluation of ALIS GPR for Humanitarian Demining in Colombia and Cambodia," in 2018 International Conference on Electromagnetics in Advanced Applications (ICEAA), 2018, pp. 114–117, doi: 10.1109/ICEAA.2018.8520518.

[5] F. Roth, P. van Genderen, and M. Verhaegen, "Analysis of the influence of mine and soil properties on features extracted from GPR data," in Proc.SPIE, Oct. 2001, vol. 4394, doi: 10.1117/12.445495.

[6] J. J. Pantoja, F. Vega, F. Román, and F. Rachidi, "Effect of Dispersive Soil on the Electromagnetic Response of Buried Wires in the UHF Range," Radio Sci., vol. 53, no. 7, pp. 895–905, Jul. 2018, doi: 10.1029/2018RS006544.

[7] Y. Hua and T. K. Sarkar, "Matrix pencil method for estimating parameters of exponentially damped/undamped sinusoids in noise," IEEE Trans. Acoust., vol. 38, no. 5, pp. 814–824, 1990, doi: 10.1109/29.56027.