Ground Penetrating Radar Radargram Filter using Singularity Expansion Method

Eder Fabian Ruiz [1*], Daniel Chaparro-Arce [1], John J. Pantoja [1,2], Felix Vega [1,2], Chaouki Kasmiv [2], and Fahad Al Yafei [2]

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

[2] Directed Energy Research Centre, Technology Innovation Institute
Abu Dhabi, United Arab Emirates

[*]edruiza@unal.edu.co

Abstract—In this paper, the singularity expansion method (SEM) is used to improve the signal-to-clutter ratio of radargrams obtained with a ground penetration radar (GPR). SEM allows to select the poles of the GPR signals corresponding to unwanted signals, clutter, and also reflections of specific buried objects. A highly reflective metallic material was used to assess the use of SEM as a tool to eliminate unwanted reflections and signals produced by a GPR. Selected clutter poles are eliminated from each frame of the SAR image in order to keep only desired poles for analysis. Finally, the reconstructed radargram obtained applying SEM is compared with the image obtained using a well-known processing technique. Results show that the proposed technique can be used to straightforwardly remove undesired signals measured with GPRs.

I. INTRODUCTION

Ground penetrating radar (GPR) is a widely used method for subsurface inspection through the analysis of reflected pulsed signals. In the last decades, it has been used for humanitarian demining in combination with metal detectors [1]. Although anti-personal mines can be detected with this technique, there are still challenges in detecting and identifying improvised explosive devices with low metallic content since similar scattered signals are measured from clutter [2]. Clutter includes unwanted signals due to antenna crosstalk, ground reflections, buried rocks reflections, among others.

Radargrams are images that are produced from scans of the GPR signals. A radargram is made up of impulse response functions (IRFs) taken in different physical positions around an axis, generating a synthetic aperture radar (SAR) image. For this reason, relevant information is not directly revealed in a radargram and mathematical processing is needed to highlight the information it generates. Clutter removal techniques include background removal, filtering, wavelet reconstruction, deconvolution, among others [4]. This variety of techniques shows that still there is not a clear tool to reduce the clutter from GPR images. In this work, singularity expansion method (SEM) is proposed for clutter removal. SEM allows the representation of a signal as a combination of exponentially damped and/or non-damped sinusoids with specific parameters (i.e., frequencies and damping factors) [3]. These singularities can provide information related to the physical characteristics of the soil and buried objects.

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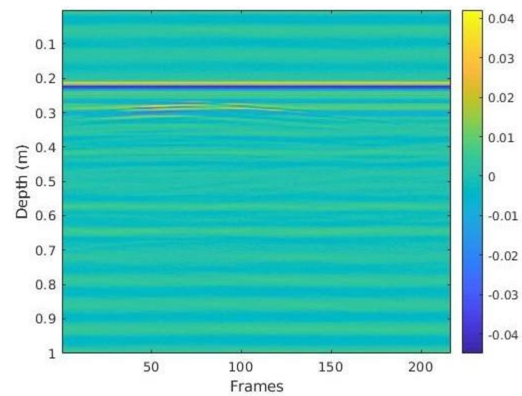

Fig. 1. Radargram obtained with raw data.

II. EXPERIMENTAL SETUP

For the experiment, an aluminum pyramid-shaped object was placed over a floor formed of a layer of ceramic and steel. Both, the pyramid and the floor present high reflectivity and both are easily visible in the SAR image. The acquisition system is composed by an Ultra-Wideband Ground Penetration Radar (GPR-UWB), a Vivaldi antenna with a bandwidth from 300 MHz to 3 GHz, and a computer. It was suspended in a XY positioning system which scans over a distance of 120 cm with a total of 216 frames during each sweep.

III. DATA PROCESSING

In Fig. 1 a raw radargram is presented. Since the same antenna is being used for transmitting and receiving, the transmitted pulse is first visualized in Fig. 1 (i.e., yellow and blue lines along the radargram). Then, lower intensity signals coming from the object and floor reflections are registered. However, the object cannot be easily appreciated in this raw data.

A. Background Removal

Background removal, which is a commonly used technique, can be applied [4]. This technique subtracts from the image the average of all the frames, which mostly represent the background. As shown in Fig. 2, some details are highlighted. Although the object now can be identified, there are also strong

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reflections from the floor and collateral reflections that can difficult the reading of this image.

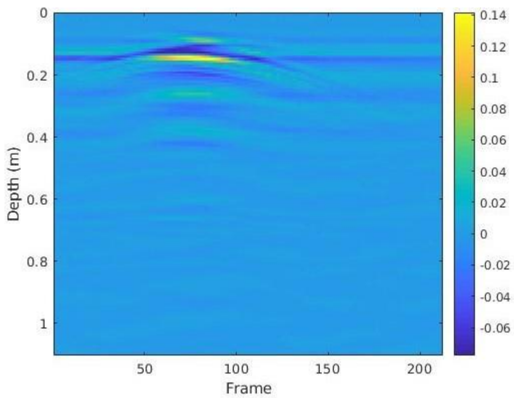

Fig. 2. Radargram using background removal as processing technique.

B. Application of SEM to the Radargram

As an alternative, the radargram was processed using SEM. A particular implementation of SEM called Matrix Pencil Method (MPM) was used [3]. This representation allows to have a set of poles that contain the signal of each frame in the complex plane. Then, the clutter poles can be identified and removed from the analysis. In our case, poles due to reflections of the laboratory floor are removed from each radargram frame. After removing undesired poles, the signal of each frame is reconstructed using 16 poles.

C. Pole Removal Method

To remove undesired poles from the signal, first unwanted poles are identified. Similar to the background removal technique, the average of all frames is calculated and its poles are taken as clutter. Then, these poles are removed from each frame. An explored alternative for pole removal is windowing the complex plane and eliminating undesired poles. This method can eliminate substantial characteristics of the signal and can produce singular matrices for closely spaced poles. Another assessed alternative is direct subtraction of poles. In this method, the average value of the complex poles of the clutter is directly subtracted from each frame. This is achieved defining the entire radargram as an A_{pm} matrix, where p is the number of poles and m the number of frames as follows:

$$\begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{p1} & \dots & a_{pn} \end{bmatrix} - \begin{bmatrix} c_1 \\ \vdots \\ c_p \end{bmatrix} = \begin{bmatrix} a_{11}-c_1 & \dots & a_{1n}-c_1 \\ \vdots & \vdots & \vdots \\ a_{p1}-c_p & \dots & a_{pn}-c_p \end{bmatrix}.$$

Then, from the reconstructed signals with a lower number of poles, a new radargram is generated. As the removal is not clean, there are subtractions that make the clutter poles to concentrate on the origin, mitigating its effect and even generating positive poles. For this reason, an additional step of applying the classical background removal technique is still required. Fig. 3 shows the radargram obtained by applying poles removal and background removal, where $1 < p < \infty$ and $m = 223$. In the figure, the object is clearly highligted from the background and the floor reflections are almost deleted. After the processing few relevant poles are maintained (i.e., less than 10) producing a sparse matrix and loss of resolution in the image.

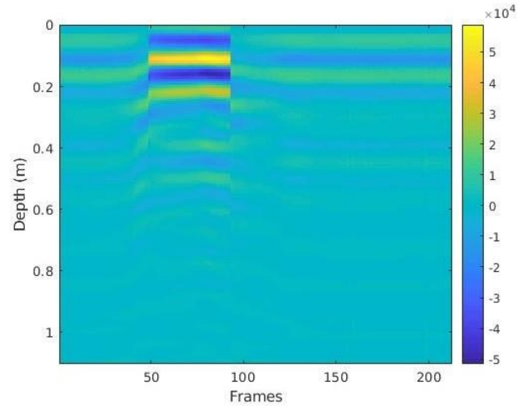

Fig. 3. Radargram using SEM and background removal.

IV. Discussion

Results show that the proposed method can generate a selective filtered radargram if the complex poles of the image are properly manipulated. The method of direct substraction of poles has the issue that generates very large gain and also introduces virtual components in frequency. Although the results presented here are preliminary, promising features of this technique, such as the elimination of known reflections, were demonstrated in this paper.

References

[1] M. Sato, K. Kikuta, and R. B. Miller, “Evaluation of ALIS GPR for Humanitarian Demining in Colombia and Cambodia,” 2018 International Conference on Electromagnetics in Advanced Applications (ICEAA), Cartagena des Indias, 2018, pp. 114-117.

[2] F. Lombardi, H. D. Griffiths, and A. Balleri, “Bistatic Radar Signature of Buried Landmines,” International Conference on Radar Systems (Radar 2017), Belfast, 2017, pp. 1-6.

[3] Y. Hua and T. K. Sarkar, “Matrix Pencil Method for Estimating Parameters of Exponentially Damped/Undamped Sinusoids in Noise,” IEEE Transactions on Acoustics, Speech and Signal Processing, vol. 38, no. 5, 1990.

[4] S. Gutierrez, F. Vega, F. A. Gonzalez, C. Baer, and J. Sachs, “Application of polarimetric features and support vector machines for classification of improvised explosive devices,” in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 11, pp. 2282-2286, Nov. 2019.