GROUND PENETRATING RADAR AND THE POSSIBILITY OF BURIED OBJECTS DETECTION

R. Grimberg, N. Iftimie, R. Steigmann, G. S. Dobrescu

Nondestructive Testing Department, National Institute of R&D for Technical Physics, Iasi, Romania

ABSTRACT

Please start with an Abstract of up to 200 words giving a brief account of the most relevant contributions of the paper. The word ABSTRACT, in Capitals, should appear as a title, as seen above (use Times New Roman, Italic Boldface 12 pt).

Key words: ground penetrating radar, buried objects, algorithms and signal processing, FDTD simulation.

1. Introduction

Ground penetrating radar (GPR) is a non-intrusive technique used to obtain information about the medium below the surface of the earth. GPR is a relatively new electromagnetic method used for detection and localization of buried objects and supplementary for a real inspection of the buried pipes, made from glass fiber polyester composite. There are a wide range of domains that have used GPR such as archaeology, geology, civil engineering and military applications. To operate successfully GPR must achieve an adequate signal to clutter ratio, an adequate signal to noise ratio, an adequate spatial resolution of the target and an adequate depth resolution of the target [1]. In the same time, besides the correct set-up of the GPR equipment, the easiness of GPR signal’s interpretation depends by the contrast between the target permittivity and the one of the soil as well as by suitable scanning direction. However, a significant limitation of GPR is that it can be very difficult for a non-expert user to extract the information about the underground from the raw data [2]. The paper purpose is to present a series of results obtained the using of GPR for detection and characterization of unexploded ordnances (UXO) and glass fiber reinforced plastic pipes that serve for steam, water and waste water transportation. The methods and the algorithms proposed were tested on case studies with the purpose of detection of UXOs and a buried pipe, made from glass fiber polyester composite with diameter of 1.3m when the survey conditions allow only the scanning along the pipe.

2. GPR principles

A radiofrequency impulse is applied to an emission antenna, placed near the ground, which generates an electromagnetic wave packet which is propagated in soil. When during the propagation it met the interface of an object having other electromagnetic properties than the soil (other dielectric permittivity and/or other magnetic permeability) the wave packet is partial
reflected, being picked up by a reception antenna and appropriate processed. A block diagram of a generic GPR system is shown in Figure 1. The transmitter can provide an amplitude frequency or phase modulated waveform signal and the selection of the bandwidth, repetition rate or mean power will depend upon the path loss and target dimensions. The transmit (Tx) and receive (Rx) antennas will be usually identical and will be elected to meet the characteristics of the generated waveform. The key of success of this method lies in proper pre-processing of the GPR data, which is a very important step before formal data analysis can begin.

Models of the GPR situation range from a simple single frequency evaluation of path losses to complete 3D time domain descriptions of the GPR and its environment. Modeling techniques include single frequency models, time domain models, ray tracing, integral techniques and discrete element methods. The Finite Difference Time Domain (FDTD) technique has become one of the popular techniques [1], [3].

![Block diagram of a generic GPR system.](image)

The GPR equipment delivers complex signals, similarly from all points of view with A scan and B scan. A collection of B scan provides complete electromagnetic information about the scanned region.

3. **Signal processing**

3.1. **A-scan processing**

An important process operation is to ensure that the mean value of the A-scan be near to zero. This assumes that the amplitude probability distribution of the A-scan is symmetric about the mean value

\[
A'_n = A_n - \frac{1}{N} \sum_{n=1}^{N} A_n
\]

where \(A_n\) - unprocessed data sample, \(A'_n\) - processed data sample, \(n\) – the sample number, \(N\) – total number of samples.

The next step in GPR signal processing is noise reduction and this can be achieved by either averaging each individual sample at the A-scan. The general effect is to reduce the variance of the white noise and gives an improvement in signal to noise ratio.

The general form of the filtering operation is given by

\[
A'_n = A_n + \frac{A_n - A'_{n-1}}{K}
\]

where \(A'_n\) is the averaged value, \(A_n\) is the current value.

The factor \(K\) may be chosen to be related to \(n\), \(N\), or a fixed value, which will weight the averaged value appropriately. Averaging has no effect on clutter.
3.2. B-scan processing

If we consider an assembly set of five samples comprising a B-scan, there are a number of approaches to signal processing which can be considered. Imaging with GPR data is frequently hampered by clutter.

The principal problem for a correct interpretation of GPR images consists in the extraction of unwanted signals as the ones due to transmission of the forward wave from Tx to Tr and those due to reflection on the air-soil interface. This operation is named background removal, a series of specific algorithms being used. The results, good enough, have been obtained using the simple procedure named subtract mean trace [4]. In this method, we define a window of L pixels and subtract the mean of the pixels from all the pixels in this window. The window is moved along and the procedure is repeated until the entire image is covered, as following

\[ g(x, y) = f(x, y) - \frac{1}{L} \sum_{i=-\frac{L}{2}}^{\frac{L}{2}} f(x + i, y) \]  

where \( g \) – filtered image, \( f \) - raw data and L is the window size.

Proceeding as in [3], the measured data are split into \( N_{\text{seg}} \) spatial segments. Over each segment we approximate the spatial resolution in both the amplitude and time delay of the ground reflection by weighted sums of Chebyshev polynomials, the domain of the segment was normalized to the interval [-1,1].

Let \( A_i(x) \) denote the spatially ground reflection amplitude and \( B_i(x) \) the time delay of the ground reflection peak over segment \( i^{th} \). We approximate \( A_i(x) \) and \( B_i(x) \) as a sum

\[ A_i(x) = \sum_{n=0}^{N_{\text{pol}}} a_n T_n(x) \]

\[ B_i(x) = \sum_{n=0}^{N_{\text{pol}}} b_n T_n(x) \]  

where \( T_n(x) \) are the Chebyshev polynomials defined by the recursive relation

\[ T_{n+1}(x) = 2T_n(x) - T_{n-1}(x) \]  

with \( T_0(x)=1 \) and \( T_1(x)=x \).

Because the reflection coefficient at the air-soil interface is typically complex, we can represent the coefficients as

\[ a_i = [a_{i,\text{real}}, a_{i,\text{imag}}, \ldots] \]

\[ b_i = [b_{i,\text{real}}, b_{i,\text{imag}}, \ldots] \]  

The frequency-domain ground reflection in spatial segment \( i^{th} \) can be estimated as

\[ G_i^{\text{est}}(x, f) = A_i(x) H(f) \exp\left(2\pi j B_i(x)\right) \]  

where \( H(f) \) is the windowed frequency response of the radar, i.e.

\[ H(f) = \tilde{H}(f) W(f) \]  

In which \( \tilde{H}(f) \) is the average frequency spectrum of the raw GPR data within the segment and \( W(f) \) is a window applied when creating the time-domain data. We have used a Hanning window. The time domain reflection estimated becomes

\[ g_i^{\text{est}}(x, t, \vec{a}, \vec{b}) = A_i(x) h(t - B_i(x)) \]  

where \( h(t) \) is the inverse Fourier transform of \( H(f) \). The measured ground reflection over segment \( i^{th} \) can be expressed as

\[ g_i^{\text{meas}}(x, t) = g_i^{\text{est}}(x, t, \vec{a}, \vec{b}) \]  

\[ n_i(x, t) \]
where \( n_i(x,t) \) represents the modeling error. The coefficients \( \vec{a}_i \) and \( \vec{b}_i \) are found by a least-square error process, which requires a nonlinear optimization of

\[
\left[ \hat{a}_i, \hat{b}_i \right] = \arg \left( \min \left\{ \left\| \hat{g}_i(x,t) - g_i^{\text{est}}(x,t,\vec{a}_i,\vec{b}_i) \right\| \right\} \right)
\]

Once the weighting coefficients \( \vec{a}_i \) and \( \vec{b}_i \) are estimated, the amplitude term \( A_i(x) \) and the delay \( B_i(x) \) of segment \( i \) are evaluated using (4).

The parameter estimation was performed using a nonlinear least square error minimization function, in the Matlab 2012b Optimization Toolbox. If the optimization routine does not converge for a data set, we must use a recursive approach. Imaging techniques can be used to focus the energy present in a point target’s hyperbolic arc back to a single point. This technique, named migration allows the determination of the depths of buried objects.

4. **The equipment and the tested region**

The GPR equipment is Utility Scan Standard System GSSI USA (Figure 2), having a 400MHz antenna. In function of the soil humidity, this system allows the investigation in depth until 4-4.5m for examination glass fiber reinforced plastic pipes or UXO.

![GPR equipment and the investigated region](image)

On the front wheel the GPR displacing system is mounted an encoder that assures the determination of the position with 1mm precision. The sampling raster is 0.04ms, the quantization being made on 16bits. The average value of dielectric permittivity of the soil was determined during the measurements, using standard procedures [5] as being 6. Each situation has been individually simulated using GPRMax2D, based of FTDT method [6]. The antenna and the electronic block is placed on a displacing system. The front wheel of the displacing system has an encoder which allows the determination of position with ±1mm precision. The equipment has been set-up to record A-scan at each 10cm, the interval for which the signals are obtained being 32ns. In the basis of previous measurements of dielectric constant of the soil from the scanned region, this has been set-up at \( \varepsilon_r = 4 \).

A region of 1000x4.5m from the Bahlui river bank, river that pass through the middle of Iasi city, Romania, has been scanned, very closely to the riverbed. In this region, the existence of a decommissioned pipe for wasted water has been suspected. The pipe has approximate 1.3m diameter and it is supposed to be made from glass polyester composite. The exact position of the pipe is unknown, maybe is buried parallel with the riverbed. Due its orientation and to the concrete scanning possibilities, the scanning has been effectuated in 7 parallel traces with 1000m length, separated between them with 0.5m, Figure 3. In order to facilitate the presentation of data, a zone of 10x3.5m has been selected. The scanning direction is probable along the pipe, the most difficult situation to be interpreted.
For an experimental tested site the GPR raw data for different types of UXO, presented in Figure 4, have been obtained. In this test site, parallelepiped holes with 1x1x0.8 m³ dimensions have been practiced, where different types of ammunition (without explosive material).

After its introduction in the hole, this was tamped with soil which has been pressed. All types of UXOs have been buried at 0.8m depth, excepting the antitank plastic mine that was buried at 0.6m, according to its indications for using it.

5. Experimental results

The data obtained during inspection were stored in the PC in .txt format, their post-processing being made according to the algorithms presented above, in Matlab 2012b. In Figure 5 a is presented an original A-scan and in Figure 5 b, is presented the same A scan after the method which made mean value to be close to zero and the noise was reduced according to eq. (2) has been applied. K has been chosen as 1.02. The original B-scan image from the scanned zone is presented in Figure 6a. To each A-scan from the Figure 5 a, the signal processing algorithm described above is applied and then, background removal with sliding window with length L=20 pixels is applied, the results being presented in Figure 6b.
The horizontal line corresponding to approximate time 10ns corresponds to the top of the pipe parallel to the scanning direction. The horizontal line placed at approximate 22.5ns corresponds to the reflection on the bottom of the pipe. The vertical zone placed between 3.2m and 3.8m to the junction between two sections of the pipe, where multiple reflections appear. The horizontal line at 21ns represents the reflections on the waste water on the bottom of the pipe. The rest of horizontal lines are due to multiple reflections on the interfaces that form the soil in the scanned zone.

Concatenating the B scan images and following the horizontal line placed at 10ns, the profile of the pipe is obtained, its diameter could be estimated (Figure 7).

Also, groups of different types of UXO have been used. The measurement conditions had remain the same in all cases: 0.05m distance between row data in A-scan, 1024 samples/cm, 0.1m distance between successive B-scans, 20dB amplification. After applying migration technique according [2], the region of maximum concentration of energy, corresponding to the real position of top surface of the kargo projectile has been emphasized. It can be observed that the migration procedure locates correct the superior part of the projectile. Concatenating the B-scan obtained after migration of corresponding GPR images of the kargo projectile and applying top view
technique, the image of the kargo is obtained and from simple measurements, the type and the dimensions of the projectile can be determined. Also, the depth at which the projectile has been buried can be determined from raw data after migration. In Figure 8a is presented the top view of a kargo projectile and in Figure 8b is presented the top view for an antitank mine MAT 62B. It must be mentioned that its shell is made from plastic, the metallic parts having a total weight of 15.8g.

Fig. 8. Top view: a) two projectile, 76mm caliber; b) antitank mine

6. Conclusions

GPR has started to be used with good results, in different types of applications, from which must be mentioned the detection of buried objects as pipes, metallic or made from dielectric materials. In order to interpret correct the images delivered by GPR, (B-scan), due to high level of noise and of clutters, it is necessary to develop a lot of specific procedures of signal and image processing. Even in extremely difficult conditions for scanning, when the terrain imposes only the scanning along the pipe, applying optimal algorithms for signal and image processing, the images become easier to interpret. Applying specific procedures of signal and image processing, the shape of UXO become visible, the type, caliber, number and their coordinate can be determined from simple measurements on the results. These procedures allow the emphasizing of antitank mines from plastic, even if the weight of metallic parts is very small.

7. Acknowledgements

This paper is partially supported by Romanian Ministry of National Education under project PN-II-ID-PCE-2012-4-0437 and Nucleus Program –Contract no. 09 43 01.

8. References