Radar pulses to image the subsurface using Ground Penetrating Radar (GPR)

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Abstract. Ground penetrating radar (GPR) is one of several non-destructive evaluation (NDE) methods for buried utilities that has been proposed and tested over the last couple of decades. This enables configuring a test system that can evaluate buried objects with a minimal disruption to environmental medium. Evanescent electromagnetic waves are inhomogeneous compounds of the near field, bound to the surface of the scattering object. These modes travel along the illuminated sample surface and exponentially decrease outside it, either in the form of lateral waves created by total internal reflection at dielectric flat interfaces and particles in metallic corrugated interfaces. One advantages of GPR is that it is able to analyze a buried object rapidly without having to contact the ground and measures the time interval between the generation of the impulse and its reception after the scattering, the results being presented in B-scan representation. This paper to present the results from a GPR survey at the scanning of a region containing a sewer pipe with unknown precise location that passes under a storage tank.

1. Introduction

GPR has the advantage of controlled radiation and measurement of free electromagnetic waves. Thus, the GPR technician can have remote access to structures, targets and material properties of investigated, promoting GPR method in engineering domains, for analyzing the state of buildings, bridges, highways, dikes or waste disposal sites [1,2].

Radar is the electromagnetic analog to ultrasound, and it has four properties which make it very practical for non-destructive testing of reinforced concrete: (1) the ability to penetrate dielectric materials (e.g. concrete, ground), (2) reflection from conducting targets (e.g. steel rebar, pipes, cables) and interfaces, (3) polarizability of the microwave signal, (4) relatively small wavelengths which render small probe sizes [3-5]. GPR might evaluate the properties of mixture materials, and radar technology offers the capability of collecting data at high speeds. GPR is a geophysical method using radar pulses to scan the underground. This non-destructive method uses electromagnetic radiation in range of radiofrequency - microwave spectrum and detects the reflected signals from under structures [6-8]. GPR is used nowadays in different domain as geophysics (to estimate under earth sediments and to determine bedrock’s depths, water grids, etc), archeology (detection of archeological efficiency of civil structures, as buildings, embankments, bridges, highways and galleries) [9-11] and forensic applications (to find buried targets and in explosive mines detection) [12-14]. GPR works by transmitting electromagnetic energy towards the targeted area and receiving the reflected signals. The transmitted EM pulses are...
reflected by the discontinuities as secondary source. The interface between two layers or surfaces with different dielectrics can be considered as discontinuity, or it could be a underground target such as an buried body. The amplitudes of the received signal by the antenna and the time of flight can determine the type and position of the discontinuity. It must be taken into consideration that the recorded arrival time is time of flight in both directions [15-18]. GPR can detect both metallic and non-metallic targets in non- or partially-conducting host materials. The main operational advantage of this technique is that the radar antennae do not need to be in contact with the surface of the earth, enabling rapid surveying [19-21].

The propagation of this radiation is strongly influenced by the electrical properties of the soil, and in particular the complex permittivity and the conductivity. The radar system amplifies and enhances the pulses which are then recorded and displayed. The amplitude and phase of the signals provide information on the scattering properties of the unknown object, and the time of flight of different signals are used in calculation of indirect depths indications to the subsurface layers or reflectors [22-25]. This paper purpose an investigation of the imaging subsurface of utility pipes using GPR images recorded with 400MHz antenna and evanescent waves by FDTD simulations data.

2. The test site
The area of the civil protection dam (located in Valea Lupului, Iasi, Romania) has been taken into consideration (Figure 1). Two sides of the basin [500x305] cm with and without the feed pipe were investigated.

![Figure 1. Top view and scanning with GPR: a) Top View sketch of the dam; b) the side with pipe into the storage dam area; c) the side without pipe into the storage dam area; d) scanning directions](image-url)

The two sets of measurements on two different side for tank of accumulation have been chose; for each set of measurements was make 6 passing with at 0.3m distance (in area with concrete) and one passing over the top of tank (on ground). How it can be seen in Figure 1 b, the 6th trace is measured after the first half of dam, that is making different angle tilting, towards the pipe. This trace is not emphasize the pipe but the signal is used in the post processing as threshold.
3. Experimental set-up and results

The GPR device is Utility Scan Standard System GSSI USA. In function of the weather conditions (ex. soil humidity), this system allows the examination in depth until [4-4.5] m [26]. The front wheel of the carriage has an encoder which permits the establishing of place with ±1 mm precision. The sampling rate is 0.04 ns. The quantization of the signal is carried out on 16 bits. The device was set-up to record A-scan at each 10 cm, the interval being 32 ns. According with preliminary measurements of dielectric constant of the soil from the scanned area, this was set-up at $\varepsilon_r = 12$. The horizontal axis of each scan represent the distance along the measuring direction [27]. The vertical axis describes the travel time from both directions of record between ground surface and the depth of reflections within the test area. These data sets record were not normalized reported one with each other in terms of time range-gain, and there zero times were difficult to establish.

In porous areas with different water content, in buried areas, tunnels, there is a variation in the propagation speed of the radar waves and strong reflections occur. Interactive Interpretation of scans are plotted in Figure 3.

![GPR radargrams record by scan of basin](image)

**Figure 2.** GPR radargrams record by scan of basin: (a) Georadar indications for a scanned area with GPR on the side of the feed pipe; (b) Georadar indications for a scanned area with GPR on a side of the basin without the feed pipe

The existence of a feed pipe under dam, with 100 cm diameter buried in one concrete canal ($\varepsilon_r = 12$), the upper side of pipe is at 10.2 ns depth has been simulated using GPRMax2D, free software that solves Maxwell’s equation using FDTD method. The post-processing of simulated data were carried out in
Matlab 2018. The site simulation was seen employing GPRMax2D Gnuplot viewer [12-14]. The results of experimental surveying are noisy images, also containing clutters. The images are processed using the process usually involved at ultrasound nondestructive testing. The B scan images are formed from A-scan signals, depending of surveyed distance and the number of sampling/meter. The noise reduction are carried out by averaging each sample of A-scan, improving the signal to noise ratio. The main issue of GPR signal processing is the correct interpretation of the results, the steps to follows being the extraction of undesirable signals due to forwarding waves from emission to reception antennas and those due to scattering at the interface air-soil.

Figure 4 emphasize the results of B-scan processing one line GPR survey of the inspection zone. Signal processing algorithm presented in [12] is used to the raw data B-scan image from the investigated area. In order to achieve background removal, sliding window having distance L=20pixels and subtract mean trace are employed, the results being presented in Figure 4a and after migration method, is shown in Figure 4b, respectively.

Figure 3. Interactive interpretation for a scanned area with GPR on the side of the supply pipe: (a) pipe; (b) hole pipe

Figure 4. B-scan processing: a) after B-scan processing and ground removal; b) after migration

The reflections on the top and respective on the bottom of concrete duct bank where the pipe is located – can be observed at the depth of approximate 10.2 ns, respectively 18.6 ns. The rest of horizontal line is owing to many more reflections on the interfaces from the surface in the scanned area and concrete duct bank of the pipe [26]. By the B scan images and the horizontal line localized at 10.2 ns, the profile of the pipe is emphasized and its diameter could be approximated (Figure 5).
4. Conclusions
The identification of underground pipes, metallic or dielectric materials are carried out employing GPR technique. Due to superior level of noise and of interferences in GPR signals, the development of specific signal and image processing procedures are required for correct interpretation of the results delivered by GPR, (B-scan). Even in extremely hard conditions for surveying of investigated area, when the site requires only the recording along the feed pipe, using optimal algorithms for signal and image processing, the images can be easily to understand. The involved post processing algorithms take into consideration also the evanescent waves, in order to increase the level the interpretation of the GPR radargrams, permitting the calculation of depth and establishment of feed pipe place, the shape being evaluated with very good precision.

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