Evaluation of GPR Detection for buried objects material with different depths and scanning angles

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Abstract. A Ground-penetrating radar (GPR) is considered an efficient non-destructive device for detecting the buried object. The GPR operation is based on the analysis of the received scattered of the transmitted signal. Its output is the two-dimensional image radiogram hyperbolic curve, this image represents the reflected signal of the buried object. To date, studies investigating targets (buried objects) have produced equivocal results. Therefore, this paper highlights the importance of the effect of changing target-detection parameters (material type, target to surface distance, size, and scan to target location angle) concerning the hyperbolic curve on the GPR experiment image. A practical model has been built for this experiment with three material types (metal, plastic, and pottery) that are buried in the sand soil. Three tests have been done for different types of material, in the different depth for each buried object of the same material. Then, changing the size of the buried object (small and big size), also, changing the location angle of the buried objects concerning the direction of the GPR scan. For these tests, the effect on the hyperbolic curve has been recognized. A MALA 1 GHz geophysical GPR system is used in these experiments. As a result, the strength of the reflected EMW changes concerning the type of material, size, depth, and location angle of the buried object.

1. Introduction

Underground detection plays a vital role in many applications such as, landmine detection, survivors uncovered under the rubble, detect relics and treasures, and detecting tunnels, groundwater, oil, and other natural resources. Many techniques have been used to detect the underground fields; electrical resistance, magnetic surveys, Laser, and Ground-penetrating radar (GPR) which is considered a non-destructive (NDTs) for the detection process.

The GPR is one of the most successful and widely-used techniques for detecting and identifying buried objects, because, it is considered as a non-destructive detection process and can detect and identify both metal and non-metal buried objects with no previous information about the object. Also, the GPR system can be updated or modified to work with a digital system for further research and improvement of the detection system.
The main parts of the GPR device system are the transmitter, receiver, control unit, and power supply with a backup battery. Both the transmitter and receiver are connected to antennas as can be seen in Figure 1. Also, the control system is used to control and synchronization of the detection signal, matching the timing signal between transmitter and receiver (Tx & Rx), monitor to display the output signal, and display all reflected signals. There are two distinct types of GPR, time-domain and frequency domain. The operation frequency is an important factor for the GPR system and it determines the penetration depth of the GPR signal also to control the resolution of the detection process [1].

The detection process depends on some parameters such as; object, medium around the object, and support software. Therefore, the GPR image or B-scan is produced by penetrates the transmitting pulses to the ground, while, measuring the time elapsed between the transmitted and the reflection of buried discontinuities, their reception back onto the surface antenna. The signal can be monitored directly or recorded for further processing [2]. Multiple frequencies and multi-offset GPR data acquisition modes are used to maximize information content and parameter retrieval capabilities of the reconstruction buried target [3].

The transmitted electromagnetic pulse suffers from attenuation and distortion during the propagation in the medium because of the absorption, dispersion, and spherical diffusion [4]. It uses wide-band electromagnetic waves to produce high-resolution subsurface images [5] and determine the dielectric constant of the soil by using the delay characteristic of the propagation signals of the soil [6,7]. Also, the GPR uses a fitting technique to determine the depth and properties of the buried object as well as the dielectric constant of the medium around the body [8]. In this context, the difference between amplitudes and velocities of the electromagnetic waves, the transmitted and reflected, is used to indicates the material types in the ground [9,10]. The extracted features from the reflected waves are played a crucial role in the detection accuracy, where, the signal strength of the metallic materials is higher than that of ceramic materials, and so on [11].

The limitations of GPR are the size and complexity of the output data. However, the uneven human experiences with the software are considered problematic [12]. Therefore, according to the human expertly skilled, there are automatic and semi-automatic detection process [13]. Also, the GPR reflected signal suffers from noise and clutter, where, the noise is due to weather conditions or from electronic - communication parts, while, the clutter is generated by surface or objects. Both noise and clutter are the main difficulties in interpreting and analyzing GPR data, and they are undesired signals and it is required to remove or reduce their effect on the detection process of the buried object.

Previous studies have demonstrated a great interest in reducing or addressing the above limitations, where, the pre-processing stage is used to eliminate or reduce its impact during the detection process [14]. Also, the wavelet conversion processing is used for noise isolation and to improve signal-to-noise ratio [15]. A neural network was used to identify buried tubes [16], and the detection performance is improved by applying a convolutional neural network (CNN) [17]. The number of

![Figure 1: Block Diagram of GPR System](image-url)
buried objects and hyperbolic curve were revealed using both a support vector machine (SVM) with a histogram of oriented gradient features (HOG) graph [18]. In [19] was used trained deep learning by object. While a convolution neural network model trained by the deep learning algorithm has made remarkable progress in many large-scale identification tasks in the field of computer vision [20]. Also, the classification of areas in the radar field with useful reflections automatically produces a high-resolution image at very low computation time [21]. Also by using real-time phase analysis technology for interpreting GPR data by defining and providing objective criteria so that objects can be classified automatically without intervention by experts [22]. The estimation of the material type using an iterative process based on the General Algorithm (GAs) and Support Vector Machine (SVM) used as the classifier was presented in [23] and the objects are classified by arranging B-scan and C-scan images on a 2D orthogonal grid map [24]. While apply faster region-based convolutional neural network (Faster-RCNN) and B-Scan of GPR significantly outperforms buried object detection with classic features [25].

The problems of the detection process are the separation of noise from the scanning of the reflected signals as well as the location of buried objects, especially when the target is very small, close to the surface, or perpendicular to the direction of the GPR.

This research sheds new light on the evaluation of the GPR detection process for different buried object materials, depth, size, and scanning angle location. Therefore, to highlight the above-mentioned problems in the detection process, image B was used with RAD Explorer software for the process of detecting buried objects.

2. Mathematical Analysis

The GPR detection process is based on the velocity difference identification of the transmitted (penetrated) signal through different media around the buried objects. This difference is caused by the difference of permittivity for different media types around objects buried. Also, the attenuation is indicated the difference in reflected amplitude caused by the difference of propagated media. Therefore, the attenuation ($\beta$) to which the transmitted and reflected signal is exposed due to propagation in the medium or multi-media can be calculated through the reflected signal, as in the following equation [26].

$$\beta = 20 \times \log_{10} \frac{A_2}{A_1}$$

Where; $A_1$ and $A_2$: the amplitude values of two adjacent peaks.

Also, the reflection ($\gamma$) occurs at the boundary of the mediums that have different properties’ and the wave is propagated through it, and can be calculated through the following equation [26];

$$\gamma_i = \sqrt{\varepsilon_i \varepsilon_{i+1}}$$

Where;

$\varepsilon_i$ and $\varepsilon_{i+1}$ – The dielectric constant of layers $i$ and $i+1$.

The delay time between transmitted and received waves are;

$$\tau = \frac{2d}{c_0 \sqrt{\varepsilon_r}}$$

Where; $c_0$ – Speed of light (speed of the wave in free space), speed of the wave in medium = $\frac{c_0}{\sqrt{\varepsilon_r}}$

$\varepsilon_r$ – Relative permittivity of the medium.

3. Experimental case study

The study area is done in the Ministry of Science and Technology-Iraq, and the practical model of buried objects has been implemented, while, the GPR system with shielded antenna of 1GHz GPR
system as in Figure 2-a, MALA model was used for testing and collecting a reflected signal of buried objects as seen in Figure 2-b.

Three tests have been carried out in this study, with various depths, sizes, and scanning angles. The collected data were done by scanning the GPR device on the top of the surface and the radargram of the reflected signals is displayed on the monitor as two-dimensional images. Each GPR image contains several hyperbolic and each buried object is represented one hyperbolic.

Three types of material (metal, plastic, and pottery) were buried with the dimensions as in Table 1, while, the GPR equipment scans the surface soil sand as seen in Figure 3.

| Table 1: The types and the dimensions of the buried objects |
|----------------|-----------------|-----------------|
| Buried object dimensions | Radius of the buried object in cm | Length of the object in cm |
| Metal item | 2.5 | 15 |
| Small Plastic item | 2.5 | 35 |
| Big plastic item | 3.5 | 25 |
| Small pottery item | 3.75 | 9 |
| Big pottery item | 7.75 | 10 |
The output of the completed scan is displayed on the monitor as a GPR image and each hyperbolic curve represented the signal buried object as seen in Figure 4.

![Image of buried objects](image1.png)

Figure 3. Buried objects in the test.

![Image of GPR device](image2.png)

The semiautomic analysis of the GPR image is done by both a skilled GPR technician and an automatic detection algorithm. A Rad Explorer has been used in this study for the interpretation of the GPR image in the detection and identification of the buried object. The traditional method used for recognizing the objects is by measuring the relative permittivity ($\varepsilon_r$) of the reflected radar waves from a buried object and the materials around it.

Where, the B image represents the total reflected signal of buried objects and other unwanted signals such as noise and other reflected signals from subsurface or direct air.

Various types of filters are used, firstly to clean image B from noise and other unwanted reflected signals, as well as highlighting image features such as pixel number and edge detection for each image to detect the buried object.

The RAD Explorer software has many types of filters, in this experiment was used the optimal filter; Time zero adjustment and Bandpass. These filters were used to remove undesired signals, then the signal to noise ratio has increased, after that, the recognize percent was increased also, as seen in Figure 5.

![GPR Image and hyperbolic curve](image3.png)

Figure 4. GPR Image and hyperbolic curve of four buried objects.
4. Results
The results were reported in three tests, the first one is dealing with different objects' materials and depth, while the second is deals with different objects' sizes. The third test is dealt with different objects size and scanning angles.

4.1 Test 1.
The test setup is based on placing four buried objects. Three buried objects were used with different types of materials (plastic, metal, and pottery) at the same depth and the fourth plastic material at a different depth which is closer depth to the surface as shown in the block diagram in Figure 6-a. The direction of the scan is perpendicular to buried objects. Then the raw data is collected and displayed on the GPR image after complete scanning. The hyperbolic curve for each buried object is appeared in the GPR image as in Figure 6-b, then the interpretation stage is considered for detection and identification processes.

![Figure 6. Test 1 GPR image of four different buried objects material.](image)

4.2 Test 2.
This test setup is the same as of test 1 setup except for the changing of the Pottery object’s size from small to big one. The setup of the four buried objects is implemented as in Figure 7-a, and the reflected signal with the GPR image is seen in Figure 7-b. Repeat the same procedure in test 1. Then determine the hyperbolic curve for each buried object after that the interpretation process is considered to identify the buried object.
4.3 Test 3.
The test setup is the same as of the test 2 setup except for the changing of the object’s size and scanning angles as in Figure 8-a. The first step in this test is to replace the first small pipe with a big plastic pipe, also change its position angle concerning the direction of the GPR scan, also the metal pipe is placed parallel towards the direction of the GPR scan. Then the reflected signals of the buried objects are collected on the GPR image as seen in Figure 8-b. Then repeat the same procedure for test_1 for the interpretation of the GPR image which includes four hyperbolic curves and each hyperbolic is a reflection of the buried target.

5. Discussion of the results
This experiment was done for the detection, identification of buried objects based on the GPR system, and a software Rad Explorer for the interpretation process of the raw data.
In Test 1, the three buried objects (plastic, metal, and potter) are placed at the same distance to the surface, while the fourth buried plastic object is placed at a different depth to the surface. The results obtained from the preliminary analysis of test 1, showed that the reflected signal of the metal pipe is stronger than those to the rest reflected signals of the buried objects (plastic and pottery) as shown in Figure 9 with the blue line and the green curve. Also, from the figure, it can see that the speed of the EM wave in the medium is 12.6 cm/ ns and the depth of the metal pipe is equal to 16 cm.
A further analysis that emerged from the raw data was a weak signal of the pottery buried object as shown in Figure 10 with a green curve.

Also, in the same test, there are two plastic pipes placed at a different depth from the surface. The raw data was reported of low levels of signal for the plastic pipes. The difference between these pipes in their depth causes the difference in signals level. Where the first pipe has a low signal than the second pipe because the second pipe is closer to the surface as shown in the green curve in Figure 11( a and b). So, the hyperbolic curve is changing according to the material types and to the depth of the buried object concerning the surface. In this part, the material types and the distance of the buried object can be recognized from the hyperbolic curves in the GPR image.
In Test 2, while, the small pottery was replaced with big size pottery, the reflected signal appears the strength of the hyperbolic curve in the GPR image in clearer as seen in Figure 12 compared to the previous result in test 1 Figure 12.

![Figure 12. Reflection signal of big pottery in test 2.](image)

As a result, the reflected signal is proportional directly to the size of the buried objects. The differences between the material types of buried objects and their direction concerning the scanning direction are highlighted in Test 3. Where this test discusses the reflection signal of the buried object when the buried object is placed at an angle toward the GPR scan. Also, the small plastic pipe was replaced with the biggest one and placed at an angle toward the direction of the scan. In this context, the third metal pipe was placed parallel to the GPR scanning direction as seen in Figure 13(a, b, c, and d).

![Figure 13](image)

a) Plastic pipe at 15 cm depth
And at angle 45o
b) Plastic pipe at 15 cm depth
at zero angle perpendicular to the scan direction
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c) Metallic pipe parallel to the Scanning direction
d) Big plastic pipe at 15 cm depth at zero angle perpendicular to the scanning direction

Figure 13. Reflection signal of four buried objects in test 3.

6. Conclusion
Ground Penetrating Radar (GPR) system is a non-destructive device used in various applications and detection of buried objects. It is considered the most important application of the GPR system. GPR device consists of software and hardware parts and it is an appropriate method with low cost, quick technique survey, efficiency in comparison to other buried technologies. It sends an electromagnetic wave (EMW) through the medium, where the speed of the EM wave is proportional inversely with the dielectric constant of the buried object. The depth of the buried object is determined by the EM wave velocity in the subsurface and the travel time of the emitted pulse between the GPR system and the buried object.

The accuracy and efficiency of the detection process depend on the hyperbolic curve in the GPR image. The outcome of this study shows that the hyperbolic curve in the GPR image for all buried objects is changing according to the material type, size, depth, and location angle of the buried objects. Strong evidence of the reflected signal with more flatness and clearer was found when the size of the buried objects is big, also for metallic more than the other type of objects. The successive increases in the intensity of the reflected signal are for the buried objects placed with the direction of the scan. So, the more EM wave intersection perpendicular to the wide area of the buried object is strong and clear of the hyperbolic curve in the GPR image.

For future work, the recognition model by using a neural network and deep learning network will be built.

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