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FDTD Simulation Bowtie Dipole Antenna to Detect Small Objects and Geometric Shape Regular and Irregular by GPR

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Key words: Ground Penetrating Radar (GPR), bowtie dipole antenna, simulation, ability, detection, objects

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Abstract: This research aims to simulate the efficiency bowtie dipole antenna to detect buried objects and their suitability in many different situations and conditions by Ground Penetrating Radar (GPR). Also, among the objectives its ability to detection regular and random objects in a geometric shape. GPR technology is very important and it is used in many applications as (Civil engineering, geophysics, geology and other applications). One of the most important steps in the work of GPR radar is to choose the type of antenna used and its ability to detect small objects. In this research, we focused on a bowtie dipole antenna and we worked on many models by simulating using programs based on the FDTD method.

INTRODUCTION

In recent years, the Nondestructive Testing (NDT) of structures and soils using GPR has become a mature technology. The particular interest in this technique is explained by several advantages when compared to other NDT techniques: the portability of the equipment because of its moderate weight, relatively low cost of the survey, the reasonable budget of the initial investment and high versatility in terms of application for different purposes and scenarios. However, the success of GPR surveys is not straightforward due to the complexity of the physical phenomena involved[1-2].

The applicability of GPR as an aid to monitoring these processes has been investigated. GPR surveys have successfully resolved the shallow depth soil and geological structure[3-5].

This study aims to present the initial results obtained in the first phase of a long-term effort to build a numerical model of the GPR operation on Mars and test dedicated signal processing algorithms on the simulated data. The simulation is based on the use of a Finite Difference Time Domain method (FDTD) and we have pointed out some of its advantages that allow us to take into account the complex features of the underground. FDTD method is used to analyze a practical GPR antenna system operating above lossy and dispersive grounds. The antenna is of the resistor-loaded bow-tie type and the analysis is made for two known soil types, namely Puerto Rico and San Antonio clay loams[6-9].

GPR is a high-resolution geophysical method which is based on the propagation of high-frequency electromagnetic waves. Three decades, since, the commercialization of GPR, the vast majority of radar instruments are now applied for civil infrastructure applications. GPR is a surface-geophysical method that depends on the emission, transmission, reflection and reception of an electromagnetic pulse and can produce continuous high-resolution profiles of the subsurface rapidly and efficiently[10, 11]. The development of imaging to estimate the electromagnetic properties of the medium include the dielectric permittivity ε (F/m) and the electrical conductivity σ (S/m) which are critical issues for a physical interpretation of the target structures.

Moreover, GPR is based on the transmission and reception of 10-2.6 GHz electromagnetic waves into the ground[12, 13]. The quantitative characterization of the shallow subsurface of the Earth is a critical issue for many environmental and societal challenges. GPR is a geophysical method based on the propagation of electromagnetic waves for the prospection of the near subsurface. GPR covers a wide range of applications in geology, hydrology and civil engineering[14].

GprMax2D was also used with the development of the code and improved to achieve the goal of this work. We have obtained satisfactory and useful results through which we can determine the type of objects as conductors or dielectrics and also the geometric shape of these objects[15].

MATERIALS AND METHODS

Description method and software

FDTD based on GPR modelling and simulation: Maxwell's electromagnetic equations that mathematically express the relations between the fundamental electromagnetic field quantities and their dependence on their sources can be used to describe all electromagnetic phenomena. The fundamental equations are acquisition methods that have to be synchronized and all referred to the same coordinate system to integrate the geometric data collected by the different techniques[16, 17]. There are four basic equations, called Maxwell equations which form the axioms of electromagnetic, these equations are the following:

$$\text{rot } \underline{H} = \underline{j} + \partial\underline{D}/\partial t \quad (1)$$

$$\text{rot } \underline{E} = -\partial\underline{B}/\partial t \quad (2)$$

$$\text{div } \underline{B} = 0 \quad (3)$$

$$\text{div } \underline{D} = \rho \quad (4)$$

Where:

- $\underline{H}$ = Vector of the magnetic field strength
- $\underline{j}$ = The current density vector
- $\partial\underline{D}$ = The time derivative of the electric displacement vector $\underline{D}$
- $\underline{E}$ = The electric field strength
- $\partial\underline{B}/\partial t$ = The time derivative of the magnetic induction a vector
- $\underline{B}$ = div is the so-called source density
- ρ = The charge density

The ultimate objective of the work which has been undertaken is to build a numerical code that can simulate with enough accuracy the operation of the GPR in an actual environment in order to evaluate the real performances of the GPR. We have selected the FDTD method to describe the wave propagation and electromagnetic coupling of the antenna with the soil.

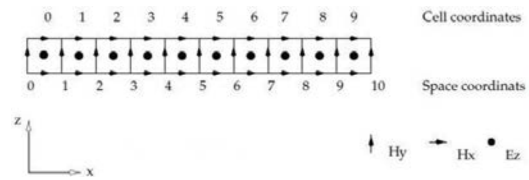

Fig. 1: The two-dimensional FDTD cell

System of GPRMax2D: The "GprMax 2/3D" is a program designed in 1996 by Antonios Giannopolos, University of York Island. Aim to a wave simulator 2D and 3D of GPR as required by using the best adapted version of the desired work. It is based on the numerical method the FDTD[18, 19].

The GprMax 2D FDTD algorithm is implemented in the plane (x-y) where the origin of the coordinate system is the lower left corner at (0, 0). The smallest space that can be allocated to represent a specific medium is a 2D cell ($\Delta x \times \Delta y$) with the reference point at its center. The space coordinates however range from the left edge of the first cell to the right edge of the last one as depicted in Fig. 1. For a given set of space coordinates (x, y), the actual positions of the EM field components are[19]:

$$\left(x+\frac{\Delta x}{2},\ y+\frac{\Delta y}{2}\right) \text{for } E_z$$

$$\left(x+\frac{\Delta x}{2},\ y\right) \text{for } H_x$$

$$\left(x,\ y+\frac{\Delta y}{2}\right) \text{for } H_y$$

which are due to the staggered arrangement of field components in the FDTD algorithm. Therefore, the interference between two cells of different constitutive parameters is located on the positions of the magnetic field components and all sources are actually located at the positions of the E_z field component[19].

Principe of GPR: Electrode magnetic the waves emitted into the ground and time measured for wave to be reflected and received (Fig. 2). When wave hits areas of change in soil, it is hit back to receiver antenna changes in soil can include objects buried underneath the surface. Depth of Investigation varies from less than a meter to over 1000 m, depending upon material properties. Detectability of a subsurface feature depends upon contrast in electrical and magnetic properties and the

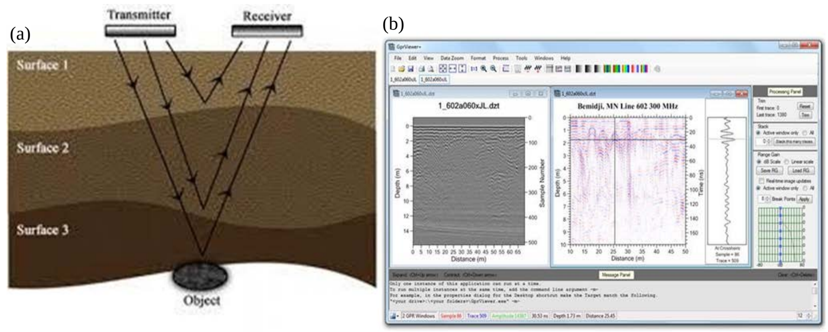

Fig. 2(a, b): General working principle of GPR

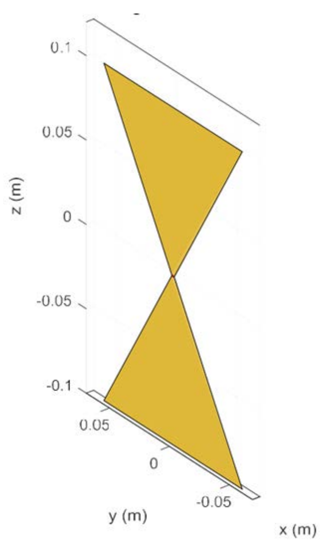

Fig. 3: The basic geometry of a typical triangular bowtie antenna

geometric relationship with the antenna. Quantitative interpretation through modeling can derive from GPR data such information as depth, orientation, size and shape of buried objects, density and water content of soils and much more. For homogeneous isotropic materials, the relative propagation speed v_r can be defined by (Fig. 3):

$$v_r = \frac{c}{\sqrt{\varepsilon_r}}(\text{m/s}) \tag{5}$$

And the depth can be calculated by:

$$d = v_r \frac{t_r}{2}(\text{m}) \tag{6}$$

Where:

ε_r = The relative permittivity
t_r = The time of sending and receiving

Bowtie antenna: Bow tie antennas are the most widely used in GPR due to their wide impedance matching and radiation properties. The bow-tie antenna has a dipole type diagram and the wave emitted by this antenna is linearly polarized. The typical gain of the bow-tie antenna is 5-6 dBi which is higher than normal dipole antennas. In addition, it can operate on a wider frequency band compared to dipole antennas or dipole antenna with a resistive load[20].

- Frequency (MHz): 400; Wavelength (mm): 749.5
- Bandwidth (MHz): 132; Distance (mm): 15.5
- Width (mm): 281.1; Height (mm): 187.4

RESULTS AND DISCUSSION

To simulate the GPR signals of objects by GprMax2d, we need a certain number of parameters such as the frequency of the antenna used, the geometry of the subsoil and targets, the dielectric permittivity, the magnetic permeability and the electrical conductivity. On a GPR image, each object below the surface appears as a hyperbola due to repeated reflections produced as the GPR unit passes over an object. In what follows, the results obtained for the different simulations carried out for different materiel as Table 1.

Buried targets in medium homogeneous: The model of simulation by GprMax2d for detection of the buried objects in soil whose characteristics (er = 8 and s = 0.0001 S/m) and along 2 m, depth 1 m (Fig. 4). Buried objects are empty and iron of various shapes (er =1 and s = 0 for empty and er =1 and s = 1010 S/m) at a depth of 0.5 m (Fig. 4ab).

Figure 4c and 4d present the radargram of detection the objects shown by hyperbolas and Fig. 3e and 3f show the race of reflection signal from the surface the objects. Notice in Fig. 4a, the first object in the form of a triangle, the second body is rectangular, the third in the form of a semicircle and the fourth as a circle. Through these forms,

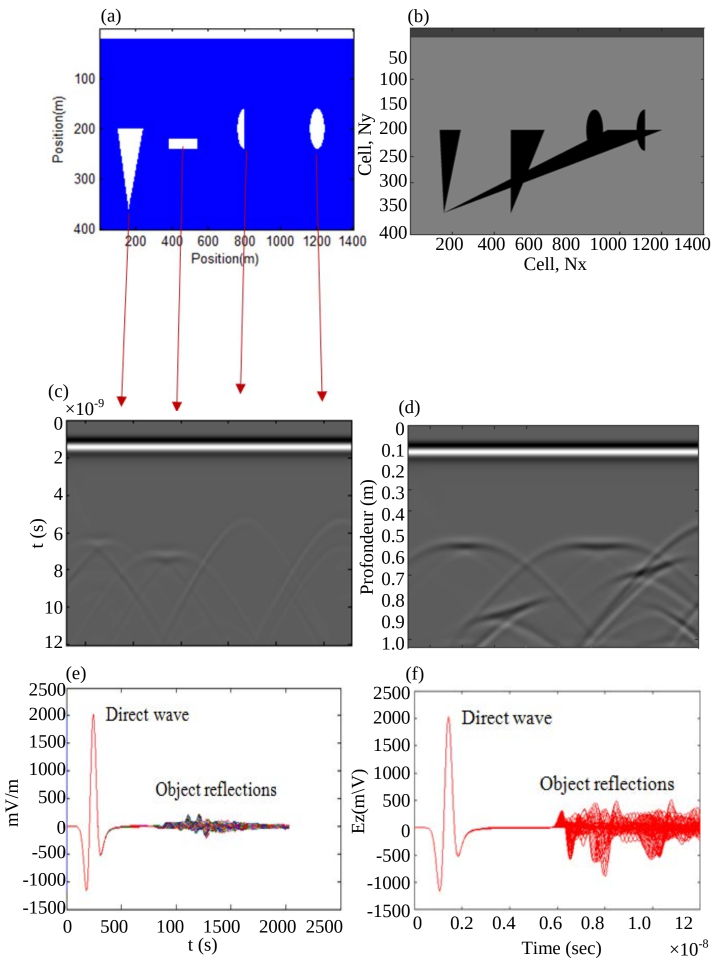

Fig. 4(a-f): Model of detection the empty and iron at f = 400 MHz (a, b) Modelling byGprMax2d (c, d) Radargrams of detect targets (e, f) Simulation GPR trace

the difference in the hyperbola (Fig. 4c) of the reflected signals from the surface of each object. In Figure 4b, we notice the presence of overlapping and irregular shapes as well. Here, there is a difference in the shape of the hyperbola (Fig. 4d) and that the radar's ability to identify and distinguish those buried objects is high.

In Fig. 5, we show a model to detect different circular objects (water, plastic, water sea, iron and empty) buried in the middle of the soil (Fig. 5a). Figure 5b presents the radargram of detection the objects as shown by hyperbolas and Fig. 5c shows the race of reflection signal from the surface the objects.

In Fig. 6, very small circular (R = 0.05) objects (concrete, iron, empty, rock) will be buried at depth 1m in a medium of soil as Fig. 6a (Ox 3m and Oy 2m) and GPR performance will be tested in detecting it and determining its depth. Figure 6b represents a radargram detection of buried objects and determine their depth through the appearance of the hyperbola. Figure 6c trace GPR signal. In Fig. 7, GPR radar performance will be tested to detect and distinguish two crossed objects buried in the medium of soil. Figure 7b represents a radargram detection of buried objects and determine their depth through the appearance of the hyperbola. Figure 7c trace GPR signal.

Table 1: Properties physical of materials used in simulation

Materials	Relative permittivity	Conductivity (s/m)	Velocity (m/ns)
wood	3	0.003	0.170
Iron	1.45	$9.99*10^6$	0.240
Empty	1	0	0.300
Dry sand	3	0.0001	0.170
Water	81	0.0005	0.030
Sea water	81	0.5-4	0.030
Plastic	4	0.002	0.150
Rock	10	0.1	0.090
Brick	4	0.001	0.150
Clay wet	20	0.1	0.067

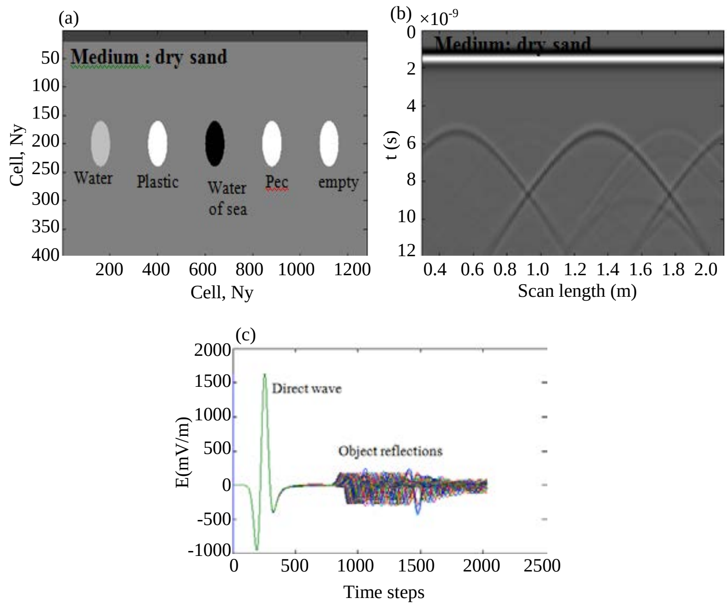

Fig. 5(a-c): Model of detection different circular objects at f = 400 MHz, (a) Modelling by GprMax2d, (b) Radargram of model detect medium contain targets and (c) Simulation GPR trace

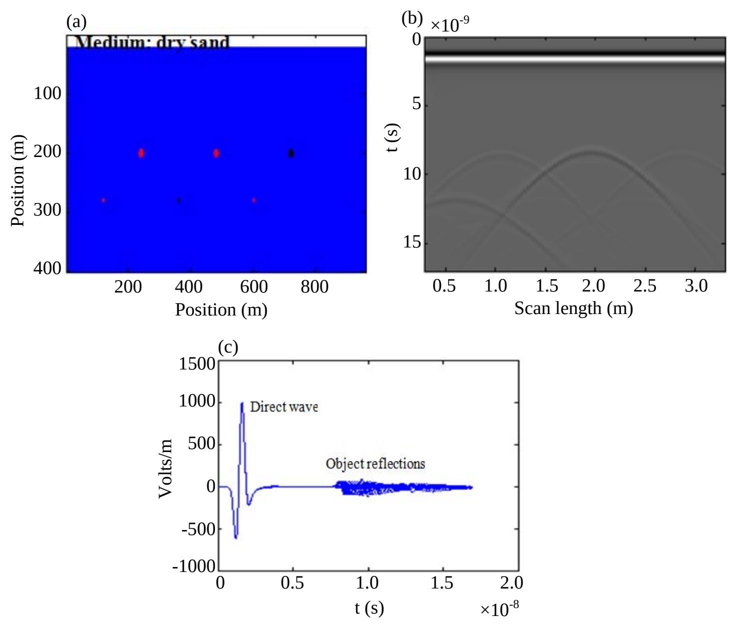

Fig. 6 (a-c): Model of soil contain small targets at f = 400 MHz, (a) Modelling by GprMax2d, (b) Radargram of model detect medium contain small targets and (c) Simulation GPR trace

Buried targets in medium (layer and targets): The study environment this time consists of layers and the geometric models of the objects to be simulated in this medium are shown in Fig. 8 and 9.

In this part, we test GPR as a tool for detecting layers and targets together in the soil. Several GPR transects were established in soil (Fig. 8 and 9). In Fig. 7a we have a group of layers and buried objects as Fig. 8a. Figure 8b and 9b represents a radargram detection of buried objects and layers through the appearance of the hyperbola. Figure 8c and 9c trace the GPR signal.

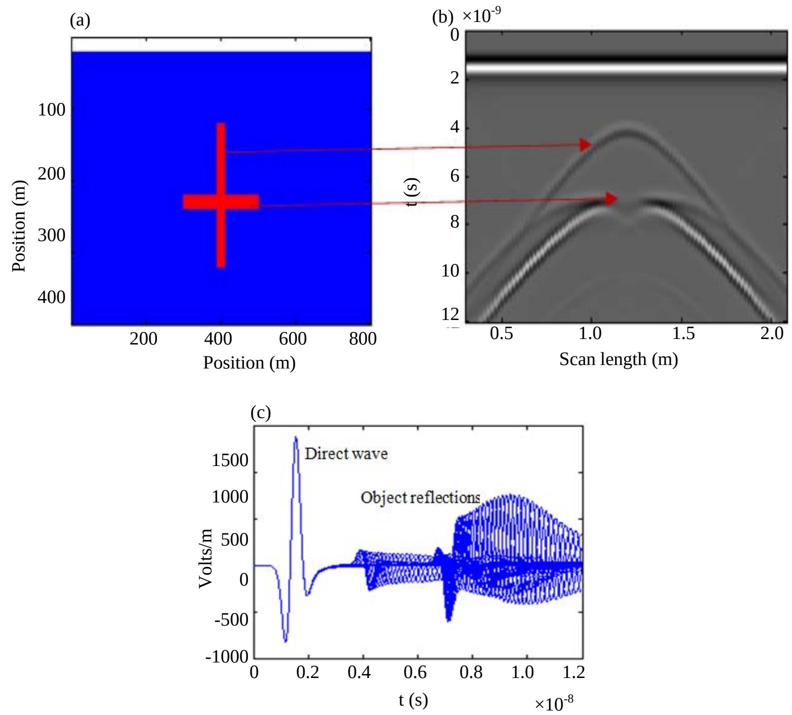

Fig. 7(a-c): Model of soil contain two targets at f = 400 MHz, (a) Modelling by GprMax2d, (b) Radargram of model detect two targets and (c) Simulation GPR trace

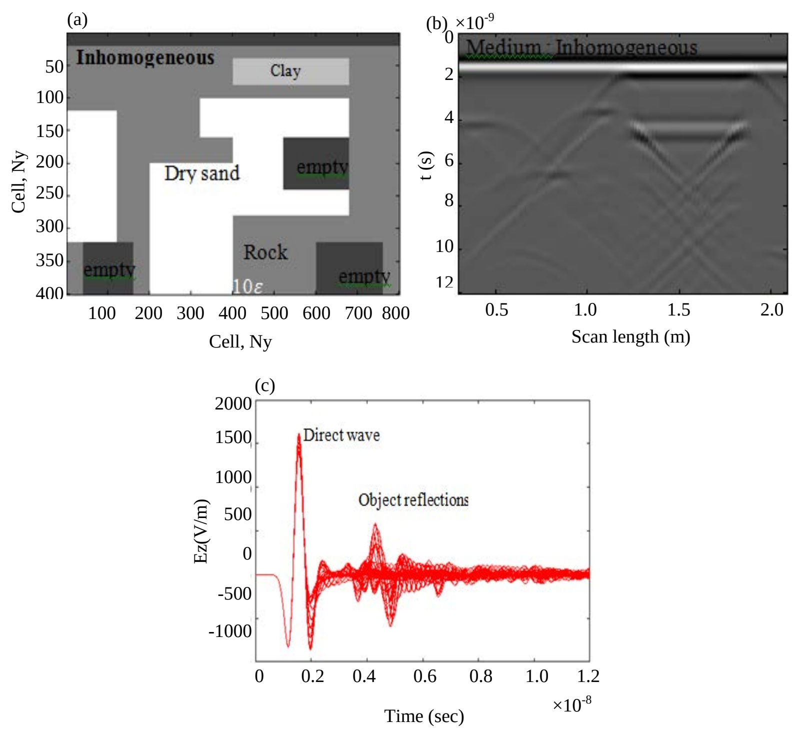

Fig. 8(a-c): Model of soil (geological) at f = 400 MHz, (a) Modelling by GprMax, (b) Radargramm of detect layer and targets and (c) Simulation GPR trace

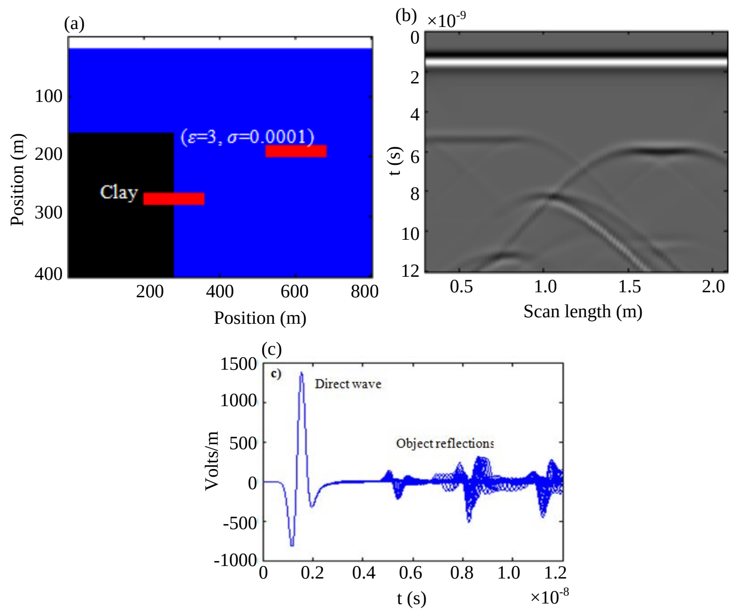

Fig. 9(a-c): Model of soil and f = 400MHz, (a) Modelling byGprMax2d, (b) Radargram of detect layer and targets and (c) Simulation GPR trace

CONCLUSION

The simulation of the signals taken by the GPR radar and ability by the software GprMax2d were successful. The simulations, we carried out relate to dielectric and conductive objects in different shapes and volumes. In all the radargrams images, simulated or obtained, one notices the presence of the indicator hyperbolas which gives information on the buried underground objects (depth, position according to the spatial directions x and y). We notice from the figures that hyperbola differs depending on the geometrical shape of the buried object and also on the physical properties of the object. Through the results obtained, the GPR ability to detect small objects buried in various conditions was very large.

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