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Underground Object Size Approximation using GPR Signal and Image Processing

S J Savita, P Anbazhagan, Abhay A Kulkarni, Danish Gufran, Andhe Pallavi

Abstract*: This paper comprises a step wise method of approximating the size of an underground object using GPR (Ground Penetrating Radar). It involves more than just using predefined filters and techniques. Usage of Trivial method of mathematics to calculate the top surface dimensions of the buried objects is the main purpose of this paper. Problem that is faced that, only the presence of any object can be known using the GPR resource, but not exactly how to derive the size of the object using the same data. This method consists of a dual approach to the problem to make sure that the data that is being given out is accurate. The objectives of this paper are to use the GPR to calculate the top surface dimension of a buried object at a suitable depth according to the frequency. The steps that are incorporated include pre-processing of raw data, determination of ROI (Region of interest) from the pre-processed data, Application of appropriate filters for image processing and estimating surface area and depth of the concealed object. The main reason of this paper is to serve the purpose of detecting what is under the ground in a quick and simpler way using the algorithm proposed.

***Keywords:* Ground Penetrating Radar-GPR, Object Size Approximation, Image Processing.**

I. INTRODUCTION

Ground-penetrating Radar (GPR) uses the disseminating Electro-Magnetic signals of a certain frequency that gets reflected by any underground buried object according to its permittivity, Reflective power, Orientation in which it is placed and the actual size of the object. Traditionally GPR [1] was used to just find out any sort of obstruction in mostly civil fields but GPR has had a revolutionary turn when it was found that it can be useful in Geological and other applications as well. However, the goal of this paper is to tweak the classical method of calculation in order to decrease the unwanted interference to show up in the GPR screen and to display the actual signal with more clarity and precision. Classical processing of GPR involves steps like filtering, pretreatment, Convoluting, and deconvoluting when necessary.

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* Correspondence Author

Mrs. S J Savita*, Assistant Professor, Department of EIE, RNSIT, Bengaluru, India.

MP. Anbazhagan, Associate Professor, Department of Civil Engineering, IISc Bengaluru, India.

Mr. Abhay A Kulkarni, Department of Electronics and Instrumentation Engineering, RNS Institute of Technology, Bengaluru, India.

Danish Gufran, Department of Electronics and Instrumentation Engineering, RNS Institute of Technology, Bengaluru, India.

Dr. Andhe Pallavi, Head, Department of Electronics and Instrumentation, RNS Institute of Technology, Bengaluru, India.

These are some of the methods we have taken into consideration along with other processing techniques. A typical GPR will consist of a transmitting antenna which generates a pulse in the desired way and gets reflected back by the objects that are presented in the subsurface of the ground. The signal needs not to travel only in the direction towards the ground, however, once the transmitter is on, the waves propagate in all the possible directions. So, it is necessary to take precautions making sure no highly sensitive EM wave reflecting objects are present in the vicinity of the experimental area. The frequency of the antenna [2] varies according to the depth at which the object might be buried. It also depends on the material that is approximated beforehand. The time that wave takes to travel from the transmitter, hit the object and return back to the receiver is called the "Travel Time". The speed with which the wave passes are a key factor in obtaining clean data which is by the relative permittivity of the object of interest and the existing background for it. There are two factors to be considered here. The permittivity of the material which affects the velocity of the Electro-magnetic wave, the attenuation, and amplitude gain is dependent on the permeability of the material buried.

II. GPR BLOCK DIAGRAM

A general block diagram of the ground penetrating radar is as shown in fig.1.

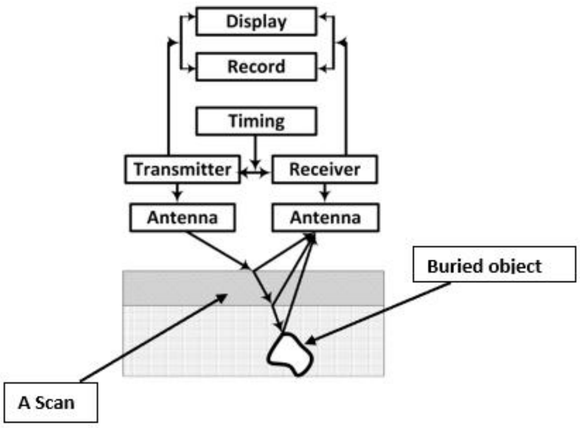


Fig. 1.1 General Block Diagram of GPR working

Ground-penetrating radar is a non-destructive technique for the evaluation of subsurface structures in the earth like landmines. It lets us detect both metallic and non-metallic objects under the surface.

It does this by broadcasting low wattage waves into the ground and timing the reflections. The GPR's operation is based on determining the dielectric content of the soil.

Ground-penetrating radar works by emitting an electromagnetic wave, which is transmitted into the ground and is reflected depending on the dielectric properties of the subsurface materials. At the surface, the reflected wave is received by the Ground-penetrating radar antenna and according to the general principle, the depth of penetration decreases as the frequency increases with an increase in resolution. The recorded signal is then registered as amplitude and polarity against two-way travel time. The signal processing of the frequency response from the radar is to implement signal retrieval and information extraction through sequential techniques.

A. GPR Display Unit

The readings obtained on the GPR's display unit are shown in fig 1.2

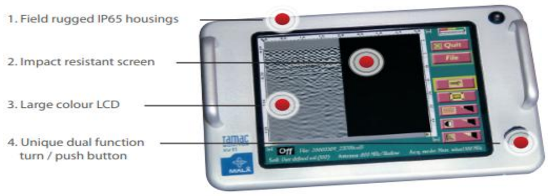
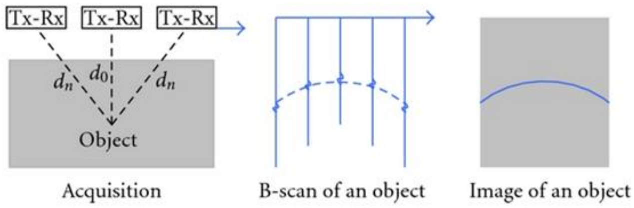


Fig 1.2 Display screen of a Ground Penetrating Radar

GPR is sensing equipment that is based on the principle of scattering of electromagnetic (EM) waves. The antenna of the GPR is selected based on the detection requirements, the antenna of the estimated frequency emits a single electromagnetic pulse, which penetrates the ground or soil as a nondispersive wave. The pulse is reflected only when there is a change in impedance. A cumulative data from the emitted pulse gives rise to a B- scan reading of the trialed area. The B - scan represented data is as shown in fig. 1.3.



Fig, 1.3 B-Scan Data

Every change in impedance is printed as a change in frequency on the GPR's display. When the pulse makes contact with a detectable object, a higher reflection takes place, this shows a spike in the data. This continuous spike draws to be a hyperbola hence, upon visual inspection of the data we can estimate all possible ROI (region of interest). The fundamental purpose of the GPR is for object detection which is as discussed. The hyperbola as projected by Fig. 1.3 demonstrates a simple reading. The GPR readings can be obtained in two modes.

1. Time triggered mode
2. Wheel triggered mode

The time-triggered mode is a simple model for collecting data. This mode is used to scan a small area for possible detections. The antenna of the unit is placed on the ground to be scanned without any physical changes in the scannable area. This ensures readings in only one selected portion. In this mode, the wheels of the GPR cart are locked and hence serve no purpose. This mode is effective in small areas of detection. The procedure to activate the time-triggered mode in the GPR is to first enable this mode before performing the task, by selecting the time triggering option in the GPR's main display.

The wheel triggered is used to cover a larger area for detection. In this mode, the wheel is triggered simultaneously with the GPR Tx-Rx antenna. The movement in the wheel records the distance moved by the GPR unit over the detectable area. The procedure to activate the wheel triggered mode in the GPR is to first enable this mode before performing the task, by selecting the wheel triggering option in the GPR's main display. After this, the antenna of the GPR unit must be pulled or pushed opposite to the mounted wheel. At most care must be taken to maintain a uniform speed of movement to obtain better results.

B. GPR Antenna

The GPR comes with a variety of antennas with different frequencies to serve different needs. Typically, a GPR antenna ranges between 10MHz to 2.6GHz. The GPR antenna consists of a transmit and receipt channel, the transmit channel emits a single pulse of the electromagnetic wave and the receipt channel records the reflected or scattered wave. The magnitude and time of the reflected wave hold key information about the reflecting body.

Table. 1.0 which shows the frequency of the antenna to be used for different materials

Table. 1.0 Various Frequency of the antenna to be used for different applications

Applications	12.5 MHz	25 MHz	50 MHz	100 MHz	200 MHz	250 MHz	500 MHz	1000 MHz
Deep Geology, Glaciology	X	X	X					
Geology			X	X	X			
Utilities, Geotechnical				X	X	X		
Archaeology						X	X	
Forensics, Snow & Ice						X	X	
Mining, Quarrying								X
Concrete, Roads, Bridges								X

Different antennas serve different purposes. Lower frequency pulses tend to penetrate the ground to a higher depth and higher frequency pulses tend to penetrate the ground to a lower depth. Hence the selecting the antenna plays a crucial role throughout the experiment. An example of a few appropriate antenna frequencies for various applications is as shown in Tab. 1.0.

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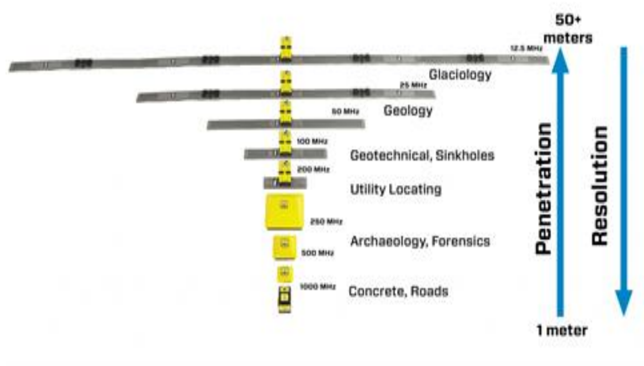

Fig. 1.4 Relation between penetration and resolution of antenna

As the penetration increases the resolution of the displayed image decreases as shown in Fig.1.4. Thus, higher frequency antennas yield a higher resolution image but cannot penetrate a greater depth into the ground. The lower frequency antennas need to undergo extensive signal and image processing to obtain better results.

III. PROCESSING OF GPR IMAGES

The processing steps of the GPR image is as shown in fig 1.5.

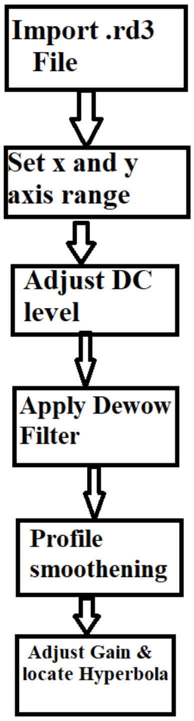

Fig. 1.5 Data Processing Block Diagram

A. Importing File

Importing a raw GPR data can be done in formats such as. rd3, rd7 depending upon the Bit processing capability of the GPR machine that was used during conducting the experiment. In this experiment, the data was imported in. rd3 format which was already preprocessed using the MALAG software provided by the equipment manufacturer.

B. Setting Axes Range

This step is to enhance the visibility of and concentrate the viewer's vision towards the possible location of the object in the frequency domain graph. Fig. 1.6 shows the data imported from preprocessing.

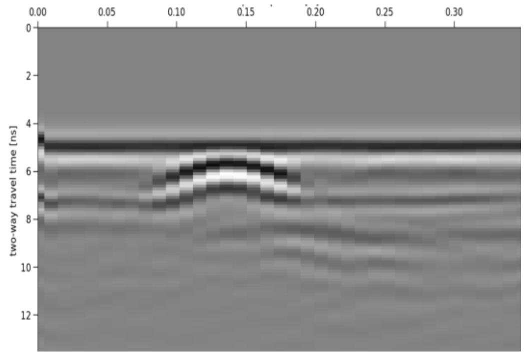

Fig. 1.6 Data imported from preprocessing

The figure 1.7 shows the selecting the region of interest according to the size of the target.

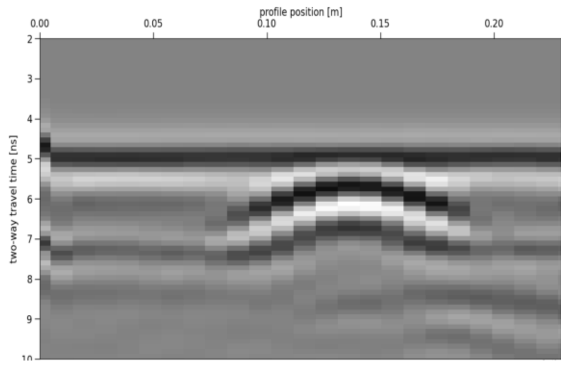

Fig. 1.7 Selecting the Region of Interest

This processing is based on the ROI concept, Region of Interest is a way of highlighting the desired region of a particular Image. The Fig 1.7 illustrates adjusting the ROI using x and y axes respectively.

C. Adjusting DC Level

DC removal is a process that is done to eliminate the noise that has occurred between the antenna and the ground interface. This helps in eliminating any external reflections caused by EM wave sensitive materials present near the antenna. Fig 1.8 illustrates the data after removal of the DC component.

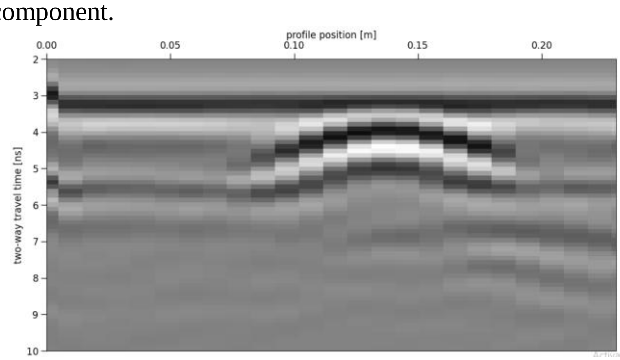

Fig. 1.8 After removal of DC Noise

D. Application of Dewow Filter

All antennas will have a certain kind of inherent and non-linear noises associated with them. These are called wow noises. Hence Dewow filter is used to remove these sensitive noises from the data. Dewow filter is an example for a High cut filter, this attenuates all low frequency noises present. Fig 1.9 shows the data after applying the Dewow filter. Fig 1.10 and 1.11 shows the difference of A scans and how the signal is stabilized with Dewow filter as compared when it is not applied.

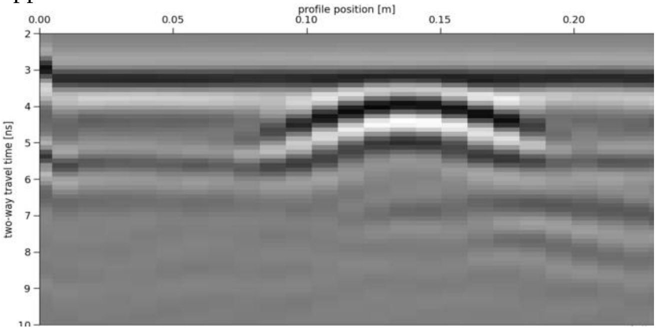

Fig. 1.9 Application of Dewow Filter

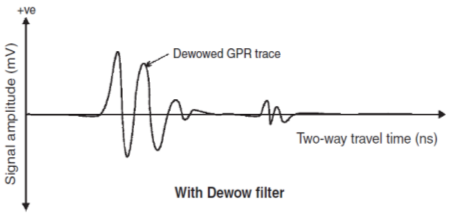

Fig. 1.10. comparison of A scans with Dewow filter

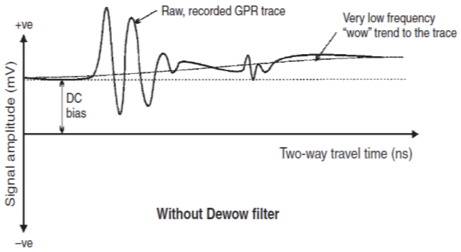

Fig. 1.11. comparison of A scans without Dewow filter

E. Profile Smoothening

This is the step to obtain the data with a less pixelated view. Profile smoothening tool is a low pass filter which smoothens the surface making it easier to recognize the hyperbola and for clear data acquisition as shown in fig 1.12.

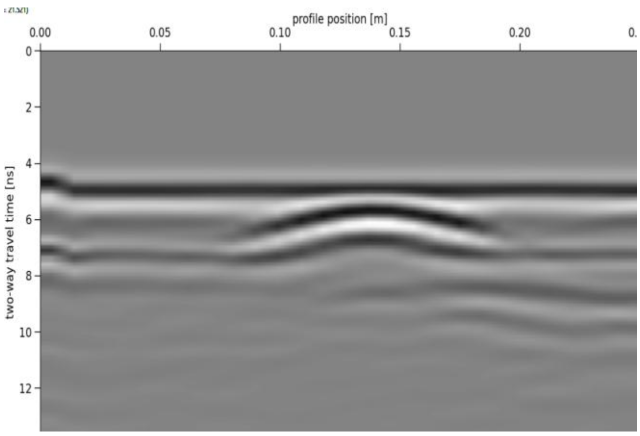

Fig. 1.12 Profile smoothening

F. Adjusting Gain and Locating Hyperbola

Gain plays an important role in the exposure of the required data in a frequency domain graph. The two types of gains that were used were

1. AGC (Automatic Gain Control) is one of the commonly applied gain correction methods. It automatically adjusts the gain for the given data set itself.

2. Tpow Gain (Time- power gain) - Inconvenience caused by the Raw data due to instant attenuation of amplitude brings the need to use Tpow gain control.

$$S\alpha(x,t) = t\alpha\ S(x,t)$$

The advantage of using the gain is the simplicity and ability to reverse the operation just by multiplying t-α. Value of the factor of t depends on each type of data. For Seismic waves α = 2, but for GPR it varies from 1-2.

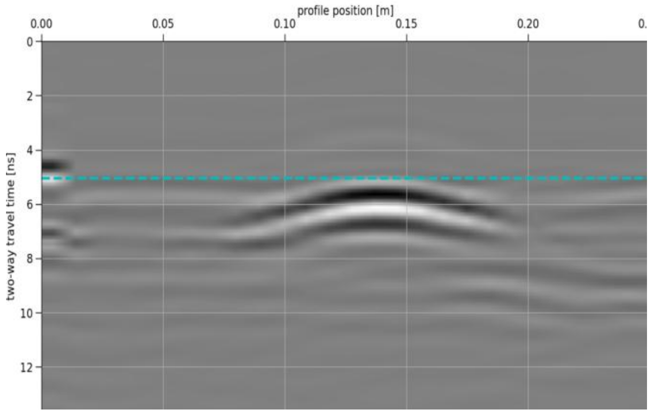

Fig. 1.12 Data after gain correction a Hyperbola Recognition

IV. CALCULATION

Based upon the obtained processed data, we need perform visual inspection and have to determine the position of the hyperbola marking. This step includes observing where the curve starts precisely and where it reaches the peak and exactly where it ends. Corresponding x axis (Profile position in m) and y axis (in two-way travel time in ns) should be carefully examined before using it. The readings considered below are extracted with reference from the above Fig 1.12. For Horizontal calculation refer the X axis and for Vertical Calculations refer Y axis.

Horizontal Top Surface Dimension Calculation

X2 = 0.177 M (Point on the X axis where the hyperbola starts -from the left side)

X1 = 0.10 M (Point on the X axis where the hyperbola ends from left towards the right)

Horizontal Distance = X2 - X1 (Difference of the values)

Horizontal Distance = 0.177 – 0.10 = 0.077m

Our research also involves the calculation of approximate depth at which the object is buried. This is done by the travel time taken by the EM wave from transmitter to the object beneath the ground,

Vertical Depth Calculation

Obtaining vertical depth accordance to the graph: (in NS)

The magnitude is divided by 2, as the rebound travel time is 2 ways.

Since, we need only one-way travel time to calculate the distance.

$(5.01 \times 10^{-9}\ s)/2 = 2.505 \times 10^{-9}$ s

We know that, $C = 3 \times 10^{8}\ ms^{-1}$

$1/c = 1/3 \times 10^{8} = 3.3 \times 10^{-9}\ m^{-1}s$ (This is taken to calculate the time taken by the signal to travel one meter)

$(2.505\ 10\text{-}9\ s)/\ 3.3 \times 10^{-9}\ m^{-1}s =$ 0 .759 m

V. RESULTS AND DISCUSSION

From the above calculations we can see that we have got 0.759 m depth theoretically. Important factor to be considered while calculating the depth is to remove the DC level beforehand, as it might affect and hinder us from obtaining accurate data. The table 1.2 shows the values obtained after measurements and calculations have been done on two objects, i.e. a mild steel plate and a metal rod.

Table.1.2 Results obtained from the method used

Targets	Approximate Dimension of the upper surface (in m)		Approximate Buried Depth (in m)		Signal to Noise Ratio	Error Percentage
	Actual Value	Obtained Value	Actual Value	Obtained Value	(in dB)	(in %)
Mild Stee l Plate	0.075	0.077	0.55	0.75	35.772	19.2
Metal Rod	0.2	0.1643	0.38	0.49	24.5734	23.17

VI. CONCLUSION AND FUTURE SCOPE

This paper proposes a method for determining the top surface area of the obscured object. This approximation finds its implications in civil and military applications. The civil uses such as detection of sewer pipes, telephone lines, and foundational construction of a building. The military applications include testing for buried land-mines and hidden fences. In conclusion, this paper focuses on identifying and calculating underground targets like steel plates and metal rods easily. This paper proposes a scope for future developments of embedded devices to perform object size approximations at a click of a button. The improvised device may employ deep learning algorithms for more efficient results.

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AUTHORS PROFILE

Mrs. S J Savita pursed MTech, from MSRIT, Bengaluru in 2010. She is currently working as Assistant Professor in Department of EIE from RNSIT, Bengaluru since 2007. Main research work focuses on Signal Processing, Image processing algorithms and interpretation of Ground penetrating radar images. She has 12 years of teaching experience.

MP. Anbazhagan pursued M.E, Ph.D, FICDM, ERF(AUS) .He is Associate Professor in Department of Civil Engineering, IISc Bengaluru.Main research interest on Engineering Seismology, Geotechnical Earthquake Engineering, Subsurface Exploration and Site Characterization.

Mr. Abhay A Kulkarni is a Final Year student pursuing his Undergraduate degree in Electronics and Instrumentation Engineering at RNS Institute of Technology, Bengaluru. India. His areas of research interest include Image Processing, Digital Signal Processing, Embedded Systems and IoT, Robotics and Automation. (Email: abhaykulkarni10@gmail.com)

Danish Gufran is a final year student at RNS Institute of Technology, Bengaluru, India. He is currently pursuing his BE in electronics and instrumentation engineering. His areas of interest are Embedded Systems, Robotics, Computer Architecture, and Digital Image Processing.

(E-mail: danishgufran12@gmail.com)

Dr.Andhe Pallavi is heading the Department of Electronics and Instrumentation at RNS Institute of Technology. She has 22 years of teaching experience. Her areas of research interest include Information Theory and Error Control Coding, Digital Signal Processing, Microcontrollers, Industrial Drives and Cryptography. She is also a life member of ISTE and ISOI societies. She has chaired sessions at several National and International Conferences. She has delivered talks at several Faculty Development Programs sponsored by UGC and TEQUIP. She is a BOS and BOE member at VTU and reputed autonomous colleges such as RVCE, BMSCE and Dr. AIT.