Model Simulation of Ground Penetrating Radar using GPRMax to Detect Porang Tuber

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***Abstract*—This study aims to design and simulate the GPR (Ground Penetrating Radar) with GPRMax software to detect the location and estimate the depth of the Porang tubers underground. The processing signal used in the GPRMax was A-Scan. The simulations were performed by varying the distance between soil surface and Porang tuber. The results of GPRMax simulation using A-scan was able to detect the location of the tuber underground. The results of the detection of Porang tuber depth showed A-scans was effective at a distance of 9 and 10 cm with error rate of less than 10%.**

***Keywords*—Porang tuber, GPRMax, A-scan signal, depth estimation**

I. Introduction

Research on the Ground Penetrating Radar (GPR) has been developed, one of which was perfomed by Tsunasaki [1]. The purpose of this study was to detect shallow-depth pipeline based on Ground Penetrating Radar. Frequency used by the author in this study was 70 - 850 MHz, while the length of the signal used was limited to 15 ns. In this study, the authors used several variations of depth to test the ability of GPR in detecting the pipes contained in the soil. The results in this study showed the pipeline depth between 0.2 m and 1.2 m in the ground was detected. Another research related to GPR was performed by Amir [2] using GPR to detect underground cable channels. The frequency used in the study was 500 MHz and amplitude of 17 dBm. In this study, the authors detected underground cables with four different soil media such as dry sand, wet sand, dry clay and wet clay.

The important parameter in the GPR system is the relative permittivity of the object to be detected. Relative permittivity describes the ability of a material to store and release EM energy in the form of an electric charge [3]. The method that can be used to find the permittivity or dielectric constant is the parallel plate method. In this method, the ratio of the capacitance with dielectric (C) to the capacitance without dielectric material (C_0) is called the dielectric constant (κ) [4]. Based on previous studies related to the ability of GPR to detect objects in the soil, GPR can also be applied to agriculture, especially in harvesting the tubers. Porang tubers have a special treatment in harvesting because the Porang plants have a dormant period where the leaves will wither and they are nowhere to be found on the ground.

Porang (Amorphophallus muelleri Blume) is one type of iles-iles plant that grows in the forest. Porang tubers potentially have high economic value. This is caused by the tuber that contains high glucomannan. There are many benefits of glucomannan flour, e.g. as a thickener in the food industry, a raw material in the paper industry, a binder in the manufacture of tablets, and others in various industries [5, 6]. To obtain whole Porang tubers, a proper harvesting technique is required, since the defect tubers (which might be injured by hoe or other equipment) could be rotten rapidly, hence, its economic values also decrease quickly [7].

Based on the above discussion, the purpose of this study was to design and model the GPR (Ground Penetrating Radar) using GPRMax software, in which it would be benefit for realization of the GPR instrument to detect the location and depth of Porang tubers underground.

II. Fundamental Theory

A. GPR (Ground Penetrating Radar)

Ground Penetrating Radar (GPR) in the field of geophysics is often known as Ground Radar or Georadar, this geophysical method uses electromagnetic wave signals. Electromagnetic waves will be emitted into the earth and recorded by the antenna when the wave has reached the surface [8]. In general, the GPR method is divided into two parts, the GPR Surface method, and the GPR Borehole method.

In the surface method, the tool simply is above ground level when taking the data. Whereas in the Borehole method, the tool is implanted between the existing object or object to be detected [9]. An estimation of the object depth in soil on GPR can be given by [10]

$$d_n = \frac{t_n.c}{2\sqrt{\varepsilon_r}} \tag{1}$$

Where d is an estimate of the object depth (m), c is the speed of light in a vacuum (m/s), t_n is the two-way travel time (the data send to and returned from the GPR) and ε_r is dielectric constant of the material. The illustration of GPR system to detect porang tuber is shown in Fig. 1

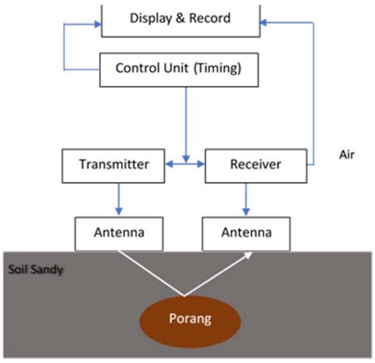

Fig. 1. Illustration of GPR System

B. *Dielectric Constant (Relative Permittivity)*

Permittivity describes the ability of a material to store and release EM energy in the form of electric charge and classically relates to the storage abilityof capacitors. The relative permittivity of a material is sometimes referred to as the 'dielectric constant' and given the symbol (κ) [5]. The use of a dielectric will increase the maximum possible potential difference between the capacitor plates [6]. Equation (2) is the equation for calculating the dielectric constant.

$$k = C/C_0 \tag{2}$$

Where k is dielectric constant value, C is the measured capacitance value after inserted the dielectric material (F), and C_0 is the measured capacitance value before inserting dielectric material (F). For a parallel plate capacitor, the expression to calculate a capacitance value can be given by

$$C = k.\varepsilon 0.A/d \tag{3}$$

Where C is the capacitance (F), κ is dielectric constant, ε_0 is vacuum permittivity of $8.85\text{x}10^{-12}$ (F/m), d is the distance between the parallel plates (m), and A is the area of the parallel plate (m^2).

III. Research Method

The process in the design of the GPR using the GPRMax 2D application was performed by collecting data in advance related to this simulation. The data included dielectric constant (κ) or relative permittivity of the material used. In determining this dielectric constant, the method was to use the concept of two parallel plates.

In this study, the authors used Ground Penetrating Radar surface method to detect Porang because this method does not damage the structure of the soil to be studied. Whereas for the software used in this research was GPRMax 2D.

A. *GPRMax*

GPRMax is open source software that simulates the propagation of electromagnetic waves, using the Finite-DifferenceTime-Domain (FDTD) method, for the numerical modelling of GPR. Current computing resources offer the opportunity to build detailed and complex FDTD models of GPR to an extent that previously was impossible. To enable these types of simulations to be more easily realised, and also to facilitate the addition of more advanced features, GPRMax has been redeveloped and significantly modernised. The original C-based code has been completely rewritten using a combination of Python and Cython programming languages. [11].

Both GPRMax2D and 3D programmes use a simple ASCII (text) file to define the model's parameters. In this file special commands are used which instruct the software to perform specific functions that are required by the type of the model the user wants to create. Some of the commands of GPRMax2D are shown in Table 1 [12].

One of the important parameters when designing on GPRMax is to determine discretization step. In rule of thumb, the discretization step should be at least ten times smaller than the smallest wavelength of the propagating electromagnetic fields. The wavelength (λ) can be given by

$$\lambda = \frac{c}{f_m\sqrt{\varepsilon_r}} \tag{4}$$

Where λ is the wavelength (m), c is speed of light (m/s), f_m is the maximum frequency, ε_r is relative permittivity. In general, the highest frequency (the maximum frequency) can be estimated three to four times of the center frequency.

B. *Parallel Plate Design*

In the designing, the things that affect the measurement of the dielectric constant using this two parallel plates method were the area of cross section of the plate and the distance between the two plates. The design of two parallel plates to measure the dielectric constant is shown in Fig. 2, which can be described here: 1)The first metal plate (it can be shifted), 2)The second metal plate, 3)Space for dielectric material, 4)Framework tool, a measuring instrument for the distance between two metal plates.

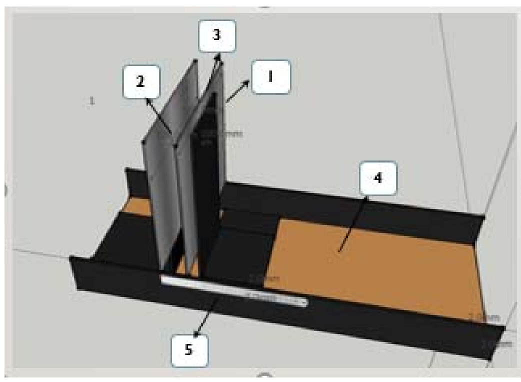

Fig. 2. Design of parallel plates

The important specification that needs to be determined when designing a parallel plate is the length and width of the metal plate. The length and width of this plate is used to calculate the value of the capacitance of both metal plates as discussed in Equation (3). The metal plates used in this study were 10 cm x 10 cm. The steps in measuring the dielectric constant using the parallel plate method is shown in Fig. 3.

TABLE I. SOME GPRMAX2D COMMANDS

Command	Function
#domain:	Controls the physical size of the model
#dx_dy:	Defines the discretization steps
#time_window:	Defines the simulated time window for the GPR trace
#medium:	Introduces the electrical properties of different media in the model
#box:	Introduce a rectangle of specific properties into the models space
#cylinder:	Like the box: but introduces a cylinder into the model
#triangle:	Like the box: but introduces a triangular patch.
#tx:	Specifies the details of a transmitter (Tx)
#rx:	Specifies the details of a receiver (Rx)
#scan:	Can be used to automatically generate B-Scans

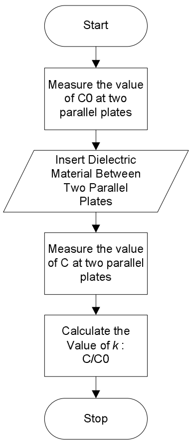

Fig. 3. Flowchart of the dielectric constant measurement

Based on flowchart in Fig. 3, the first step in measuring the dielectric constant of a material was to measure the value of C_0 using a multimeter on two parallel plates. The value of C_0 was the value of the plate capacitance before inserting the dielectric material.

The second step was to put the dielectric material between the parallel plates. In this case, the dielectric materials to be tested were paper, Cilembu tuber, Suweg tuber and Porang tuber. The distance between the two plates should be the same on the measurement of the first and second steps. If the dielectric material has been inserted between the two parallel plates, the next step was to measure the capacitance (C), then the dielectric constant based on Equation (2) was determined.

C. GPRMax Design and Simulation

The design specifications that will be simulated in this study are shown in Table 2

TABLE II. DESIGN SPESIFICATION OF GPR

Item	Specification
Radius of Porang tuber	10 cm
Size of soil	60 cm x 60 cm
Depth of Porang tuber	6 cm, 7 cm, 8 cm, 9 cm, 10 cm
Time window	20 ns
Center frequency	1.7 GHz

The next step in designing GPR using the GPRMax 2D application was to determine the command used in this study. The commands used in this study were domain size, spatial step, Porang shape, soil size, and time window.

1) Determining the Domain (#domain)

The domain in GPRMax is the dimension for the whole system that will be designed and simulated on GPRMax. The format on GPRMax for #domain is given by

#domain : f1 f2 f3

Where f1 f2 f3 are the size of the model in the x, y, and z directions respectively.

Due to the specification of GPR system to be simulated 60 cm x 60 cm, then for #domain will be written as:

#domain : 0.6 0.6 0.0013 (size changed in meters on GPRMax)

2) Determining Spatial Step (#dx_dy_dz)

The format spatial step (#dx_dy_dz) on GPRMax is given by

#dx_dy_dz : f1 f2 f3

Where f1 is the spatial step in the x direction (Δx), f2 is the spatial step in the y direction (Δy) and f3 is the spatial step in the z direction (Δz)

The first step, we determined the highest frequency (Maximum Frequency). In general, the highest frequency can be estimated three to four times of the center frequency.

$$f_m = 3\ x\ f_c$$

$$f_m = 3\ x\ 1.7\ GHz$$

$$f_m = 5.1\ GHz$$

The next step, we determined the wavelength (λ) using Equation (4)

$$\lambda = \frac{c}{f_m\sqrt{\varepsilon_r}}$$

$$\lambda = \frac{3\ x\ 10^8\ m/s}{5.1\ GHz\sqrt{20}}$$

$$\lambda = 0.013$$

In rule of thumb, the discretization step should be at least ten times smaller than the smallest wavelength of the propagating electromagnetic fields.

$$\Delta l = \frac{\lambda}{10}$$

$$\Delta l = \frac{0.013}{10} = 0.0013\ m$$

The listing of spatial step can be written :

#dx_dy_dz : 0.0013 0.0013 0.0013

3) Determining size of soil and shape of porang

In designing on GPRMax 2D, the ground size has been specified in the #box format and for porang tuber tuber specified in the #cylinder format.

#box : f1 f2 f3 f4 f5 f6 str1

Where f1, f2, f3 are the lower left of (x,y,z) coordinates, f4, f5, f6 are the upper right of (x,y,z) coordinates, and str1 is the material used.

#cylinder : f1 f2 f3 f4 f5 f6 f7 str1

Where f1, f2, f3 are the coordinates (x,y,z) of the centre of one face of the cylinder, and f4 f5 f6 are the coordinates (x,y,z) of the centre of the other face, f7 is radius of Porang, and str1 is a material used.

The listing can be written as:

#box : 0 0 0 0.6 0.6 0.0013 soil

#cylinder : 0.3 0.2 0 0.3 0.2 0.0013 0.1 Porang

4) Determining Time window (#time_window)

The time window specification is limited to 20 ns and for writing on GPRMax, the listing can be written as:

#time_window : 20e-9

IV. Result and Discussion

A. Determining of Dielectric Constant

The measurement of dielectric constants in this study were performed on several dielectric materials such as paper, Suweg tuber, Cilembu tuber, and Porang tuber. The result of capacitance measurement by parallel plates method, for paper are shown in Table 3.

TABLE III. The Results of Capacitance Measurement of Paper

	Co (nF)	C (nF)		Co (nF)	C (nF)
1	0.05	0.17	11	0.04	0.16
2	0.05	0.17	12	0.04	0.16
3	0.05	0.17	13	0.04	0.16
4	0.05	0.17	14	0.05	0.16
5	0.05	0.17	15	0.04	0.17
6	0.05	0.16	16	0.05	0.17
7	0.05	0.16	17	0.05	0.17
8	0.05	0.16	18	0.04	0.17
9	0.05	0.16	19	0.04	0.17
10	0.05	0.16	20	0.05	0.17
Average				0.047	0.1655

The calculation of the dielectric constant or relative permittivity of paper is shown in the following:

$$k = \frac{C}{C_0}$$

$$k = \frac{0,1655}{0,47}$$

$$k = 3.52$$

Thus, the (κ) value for the dielectric constant of paper material obtained was 3.52. When it compared with the value of paper dielectric constant, the measurement result using the parallel plate method has an error 0.56 %. This comparison was a reference for the feasibility of this tool used to find the dielectric constant value of the other materials. Besides testing paper dielectric constant, the others experiment in this research were testing to find dielectric constant of porang tuber, cilembu tuber, and suweg tuber. Each object in this research has been performed 20 times experiment. In the measurement for the Suweg tuber, the value obtained was 14.886. In the measurement for Cilembu tuber, the value obtained was 11.136. In the measurement for Porang tuber, the value obtained was 8.66.

B. GPRMax Model Simulation

The depth of the porang tubers used in this study were 6 up to 10 cm from the soil or ground surface. One of the depth detection visualization of the porang tubers is shown in the Fig. 3. The coordinates shown in Fig. 3 were named as ABCs (absorbing boundary conditions) of GPR system. The function of ABCs was to limit computational calculations in GPR system. The explanation of Fig. 4 i.e.: x coordinate was ABCs of GPR system on x axis, y coordinate was ABCs of GPR system on y axis, or the depth of Porang that could be seen on this axis, Tx was transmitter of GPR antenna, and Rx was the receiver of GPR antenna. The circle shape was the illustration of the Porang tuber in the model simulation, the red and blue waves were electromagnetic waves emitted by GPR antenna, soil and air were the illustration of the soil medium and air in GPR simulation, respectively.

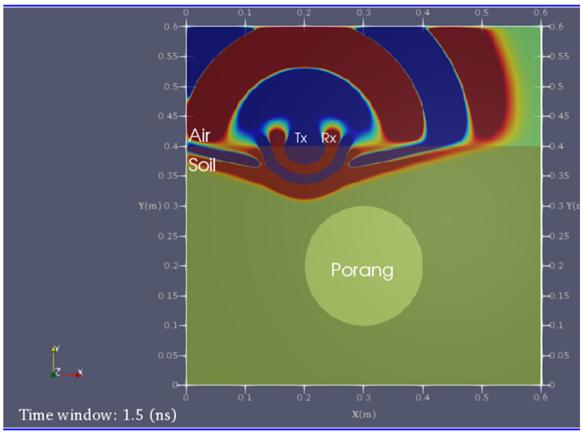

Fig. 4. The depth detection visualization of the Porang tubers

In this simulation, the processing signal used for the detection of porang tuber was the A-scan processing signal. A-scan is a single trace signal that displays the results of data processing on GPR. One result for A-scan depth detection of porang tuber is shown in Fig. 5, where the x coordinate is the travel time of the GPR system and the y coordinates are the value of electric field.

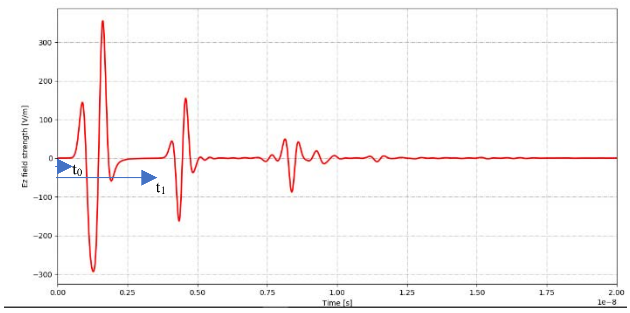

Fig. 5. A-scan of 10 cm of the Porang tuber depth

From the results of the A-scan signal in Fig. 4, the data obtained to calculate the depth estimate of porang were t_0 and t_1. Wherein t_0 was the time of the receiver to capture signals from the transmitter directly, and t_1 was the time of the receiver to read objects in the ground. The object detected in the soil was Porang. The depth estimation of Porang tuber based on Fig. 4 can be calculated using Equation (1):

$$d = \frac{t_n . c}{2\sqrt{\varepsilon_r}}$$

$$d = \frac{(t_1 - t_0) . c}{2\sqrt{\varepsilon_r}}$$

$$d = \frac{(3.6 - 0.4)\ ns\ .\ 3x10^8 m/s}{2\sqrt{20}}$$

$$d = 10.7257\ m$$

Thus, the estimation of Porang depth was 10.72 cm, and it had an error of 6.77 %. The other simulations were to perform the A-scan process for the Porang depth estimation of 6 cm, 7 cm, 8 cm and 9 cm. The result of the simulations is shown in Table 4.

TABLE IV. THE RESULTS OF THE ESTIMATION OF PORANG DEPTH (FREQUENCY OF 1.7 GHZ)

Distance of Porang from Soil Surface (cm)	t_0 (ns)	t_1 (ns)	Estimatian Porang Depth (cm)	% Error
6	0.4	2.6	7.373919	18.63%
7	0.4	2.86	8.245382	15.10%
8	0.4	3.1	9.04981	11.60%
9	0.4	3.3	9.720166	7.41%
10	0.4	3.6	10.7257	6.77%

Based on Table. 4, the deeper the Porang tubers distance detected, the longer the travel time required. The GPR system required time travel of 3.6 ns when it detected 10 cm in depth, and the GPR system required time of 2.6 ns when it detected 6 cm in depth. The results of the detection of Porang tuber depth showed that the A-scan was effective at a distance of 9 and 10 cm with an error of less than 10 %. Meanwhile, if the distance to be detected was less than 9 cm, an error of above 10 % was obtained. The errors generated during the simulation using A-scan to detect the estimated depth of Porang, were relatively high, since A-scan only read signal at one point (it can be seen on Fig. 3), this caused the process of detecting the Porang tuber was not right on the upper side of the tuber.

The simulation using the centre frequency of the GPR system of 1 GHz, 1.5 GHz, 1.9 GHz and 2 GHz were also performed. The result of A-scan depth detection of Porang tuber from frequency of 1 GHz is shown in Fig. 6.

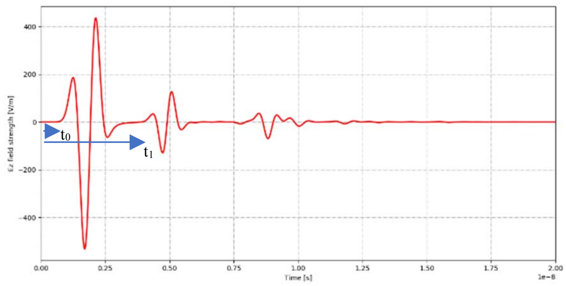

Fig. 6. Results of A-scan of 10 cm of the Porang tuber depth detection at 1 GHz

The depth estimation of Porang tuber based on Fig. 5 can be calculated using Equation (1):

$$d = \frac{t_n . c}{2\sqrt{\varepsilon_r}}$$

$$d = \frac{(t_1 - t_0) . c}{2\sqrt{\varepsilon_r}}$$

$$d = \frac{(3.9 - 0.55)\ ns\ .\ 3x10^8 m/s}{2\sqrt{20}}$$

$$d = 11.2285\ m$$

Hence, the estimation of Porang depth was 11.2285 cm, and it showed an error of 10.94 %. The complete simulation at frequency of 1 GHz is shown in Table 5.

TABLE V. THE RESULTS OF THE ESTIMATION OF PORANG DEPTH (FREQUENCY OF 1 GHZ)

Distance of Porang from Soil Surface (cm)	t_0 (ns)	t_1 (ns)	Estimatian Porang Depth (cm)	% error
6	0.55	3.038	8.3392	28.05%
7	0.55	3.238	9.0095	22.30%
8	0.55	3.415	9.6029	16.69%
9	0.55	3.7	10.5581	14.76%
10	0.55	3.9	11.2285	10.94%

The model simulation of A-scan detection for 10 cm depth at frequency of 1.5 GHz, 1.9 GHz, and 2 GHz showed errors of 10.14 %, 6.77 %, and 8.76 %, respectively.

These results show that the frequency of 1.7 and 1.9 GHz had the least estimation error, since they were the selected ones representing the Porang tubers frequency responses (range between 1.7 up to 1.9 GHz [7]).

V. CONCLUSION

From the results of this research, the measurement of dielectric constants has successfully shown some values. The parallel plates measurement of paper found the dielectric constant of 3.52 with an error measurement of 0.56 %, and the measurement of Porang tuber showed the dielectric constant of 8.66. This set up measurement could also be useful to determine the physical property i.e. dielectric constant of other tubers.

GPRMax model simulation using A-scan was able to detect the location of Porang tuber in the soil. The results using A-scan were effective at 1.7 GHz, at a distance of 9 and 10 cm with an error of less than 8 %, otherwise the distance of less than 9 cm generated an error of above 10 %. The errors generated during the simulation using A-scan due to the reading process with A-scan was only at one point. Therefore, the detection of Porang was not exactly right on the upper side of tuber.

The weakness of signal processing using A-scan in GPRMax can be solved using B-scan procedure. Signal processing using B-scan can perform multiple tracing signals simultaneously, thus determining the location of the object can be determined precisely. The report regarding the B-scan will be published elsewhere.

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