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Factors Affecting the Ground Penetrating Radar (GPR) Dataset

[1]Warishah Abdul Wahab, [2]Wan Zaini Zakaria, [3]Rohayu Che Omar, [4]Jasmee Jaafar, [5]Hairin Taha, [6]Rasyikin Roslan

Abstract--*The existing data on a subsurface utility that includes depth, position, type and material is essential information for any land development specifically involving subsurface utility maintenance, installation, and construction project. Incorrect information may result in possible damage to the subsurface utility during land development activities. Several non-destructive methods were developed in recent years to detect subsurface objects. Ground Penetrating Radar (GPR) is one of the latest technology to be used to detect subsurface utilities. This technique penetrates the subsurface and identifies the object below the ground by radio wave method, including the traces of metallic and non-metallic material at a precise location. Although this method provides an excellent advantage for the related sector, nonetheless, the surveyor needs to consider several factors such as the time window and point interval before using GPR for the detection task. This study investigates the impact of the antenna frequency, equipment parameters, and the depth of underground utility on the GPR observation results in term of accuracy. The results showed that the GPR image and the hyperbola form of the pipe influenced by the different antenna frequency, equipment parameter setting (time window and point interval), different GPR models and the depth of the buried pipeline.*

Key words--*subsurface utility; GPR; frequency; radargram; time window, point interval*

I. INTRODUCTION

Utility documents or maps that are old and dated are susceptible to inaccurate measurement and location, which may result in risky development. It is difficult to interpret the old records and for surveyors and engineers, which is also time-consuming [1].

The information of existing subsurface utility such as position (x, y, and depth), material and type are necessary for land development activities, especially during construction and excavation work [2, 3]. Accurate data used as references can prevent or at least minimize the hazardous situation while digging, disruption and damage to the underground utility [4].

As a result of trenching and excavation activities, several untoward accidents can happen. Most of the casualties and the victims involved were usually the construction workers and members of the public who are nearby the area during the incident time [5]. A research stated that significant factors contributing to subsurface utility

[1]*Institute of Energy Infrastructure,Universiti Tenaga Nasional, Kajang, Malaysia, warishah.wahab@uniten.edu.m*
[2]*Institute of Energy Infrastructure,Universiti Tenaga Nasional, Kajang, Malaysia, WanZaini@uniten.edu.my*
[3]*Institute of Energy Infrastructure,Universiti Tenaga Nasional, Kajang, Malaysia, Rohayu@uniten.edu.my*
[4]*Universiti Teknologi MARA, Shah Alam, Malaysia., jasmee2004@yahoo.com*
[5]*Institute of Energy Infrastructure,Universiti Tenaga Nasional, Kajang, Malaysia, Hairin@uniten.edu.my*
[6]*Institute of Energy Infrastructure,Universiti Tenaga Nasional, Kajang, Malaysia, Rasyikin@uniten.edu.my*

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disruption include inadequate data, incorrect survey, obsolete data and the unqualified party who do the survey work including the new setup based on survey and detection work which were inaccurate [6, 7].

The year 2002 to 2010, the statistics showed that approximately 20 individuals annually suffer from pipeline excavation operations globally, caused over 525,000 incidents and it reported in 2010 that the United States cost nearly USD900 million worth of damage [8, 9]. The ruptured pipeline that transfers crude oil cause the oil spill incident that happened in 2007 at British Columbia, Canada, subjected to inefficient pipeline labelled correctly before excavation [10].

The six-meter underground gas pipeline exploded due to the construction in Ghislenghien Industrial Park, Belgium, on 30 July 2004 (Fig. 1), which has caused 24 deaths, 120 serious injuries, one police officer and five firefighters perished. The damage costs were almost 100 million EUR [11, 12, 13].

Figure 1. The Ghislenghien Industrial Park pipeline collapse occurred on 30 July 2004 [11]

The gas line accidentally ripped by the excavator during the installation of fibre optic cable work in San Francisco Neighborhood was recorded on 6 February 2019 by CBS Local [14] as shown in Fig. 2. a neighbourhood on February 6, 2019 [14]

Figure 2. A massive rupture of the gas line in San Francisco

From the reported cases and incidents, it was evident that the correct data and information of the underground utilities and their locations is essential before the initiation of any construction phases and development to prevent any injuries to human life and avoid costly destruction to the service itself.

Numerous non-destructive for subsurface detection equipment methods such as metal detector [15], infrared thermography [16], acoustic pipe locator [17], pipe and cable locator (PCL) [18], and GPR tool [4] are the tools to detect the subsurface utility lines. Previous research showed that the GPR technology is the latest method used most commonly for detecting and mapping of subsurface utilities [4].

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Production of utility maps portrays the GPR principle in subsurface utility detection shows numerous models, varies, congested between the places, while the sizes of materials used for the installation of the subsurface utilities which shows different positioned at multiple depths [4]. This utility map can be used by the operators to execute repair work or on-site installation, especially when it involves excavation in the city and urban areas with various types of utilities filling up the subsurface as Fig. 3.

Figure 3: The 2D Subsurface Utility Map [19]

The transmitter, antenna, receiver, control unit, and monitor are the five essential components of GPR [20, 21]. The transmitter sends the frequency of the EM wave (10 MHz to 1000 MHz) to the ground for in-depth propagation to create the image of the subsurface [22]. Once the wave reaches the objects in the underground with different dielectric constants, the difference in the reflected signal is sent back and recorded by the antenna [23]. As a function of time, the receiver estimates the transmitter signal [24]. Then the sub-surface conditions are evaluated based on the amplitude of the reflected signals and time delays. The distance-measuring echo may lead to a wave delay [25]. The receiver collects the reflected waves.

The control unit measures the difference in travel time between the transmitted and received pulse and its amplitude. The amplitude depending on the travel time to portrayed on the control unit. If the measurements carried out over locations that are sequent, a media profile is presented continuously [26]. The pulse is reflected differently on the subsurface with different electrical properties and shown in the display unit as anomalies [27] as illustrated in Fig. 4. Fig. 4 shows the radar calculates the time for the pulse to be transmitted from the transmitter to the object underneath the ground and reflects the pulse to the receiver. The processor will processes the signal received, and then the target depth and location of the buried object is displayed on the display unit [28].

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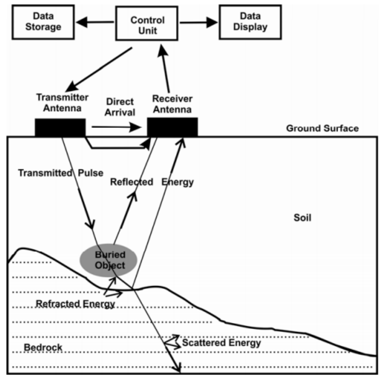

Figure 4: The GPR Principle [27]

Many GPR products are presently available on the market, such as Ingegneria Dei Sistemi (IDS), MALA Geoscience, Geophysical Survey System Inc. (GSSI), Geoscanner AB, Sensor & Software Inc. and others [20]. The limitations and capacities of each GPR are. The typical GPR equipment on the market shows as Fig. 5.

Figure 5: Sensor & Software Inc. product (Noggin Plus 250 SmartCart) [29]

GPR has several advantages to locate buried objects over other non-destructive methods such as a more advanced depth estimation of any recognized features if the soil conditions correctly identified including metal and non-metallic components [30, 31]. Therefore, GPR can be used to assess and map objects appearing in the subsurface, subjected to requirements before starting a detection process using GPR such as antenna frequency, the setting of the point interval, time-window, velocity, depth, and the model types [3233].

Detailed and interpreted image resolution can be provided based on the used of different antennas influence the delivery of different types of frequencies, and the depth of penetration based on high frequencies rate gets the higher signal and penetrate the medium much lesser. The selection of antenna frequency depends on the depth and application requirements [33]. Table 1 shows the relationship between antenna frequency, their use and the maximum intensity of detection referring to the GPR frequency, Due to that, to explore the capabilities of GPR for assessment of the factor in Table 1, this paper discusses the GPR observation results (GPR image) related to the Table 1.

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Table 1: The Correlation Between Antenna Frequency, The Applications And Maximum Depth Of Penetration [34]

GPR Frequency	Max. Depth (m)	Field/Applications
2600 MHz	0.0 - 0.40	For assessment of concrete
2000MHz	0.0 - 0.40	For assessment of concrete
1600MHz	0.0 - 0.50	For assessment of concrete
900MHz	0.0 - 1.00	For concrete assessment and void detection
400MHz	0.0 - 4.00	Subsurface utility detection, environmental purposes, engineering, detection of void
270MHz	0.0 - 6.00	Geotechnical detection, engineering and subsurface utility detection
200MHz	0.0 - 9.00	Geotechnical detection, environmental purposes, and engineering,
100MHz	2.0 - 15.00	Engineering, geotechnical detection, mine detection
16-80MHz	0.0 - 50.00	Geotechnical detection
2.0GHz	0.0 - 0.75	Assessing the road condition and pavement thickness
1.0GHz	0.0 - 0.90	Bridge Deck and Highway Evaluations

II. MATERIAL AND METHOD

Study Area

These test base with the length, width and depth (10 m x 10 m x 3 m) as Fig. 6 and the illustration of pipes and cables positioned from the top view shown as Fig. 7 tested at Makmal Ujian Alat Pengesanan Utiliti Bawah Tanah (test base) in Jabatan Ukur dan Pemetaan Malaysia (JUPEM), Wilayah Persekutuan Kuala Lumpur.

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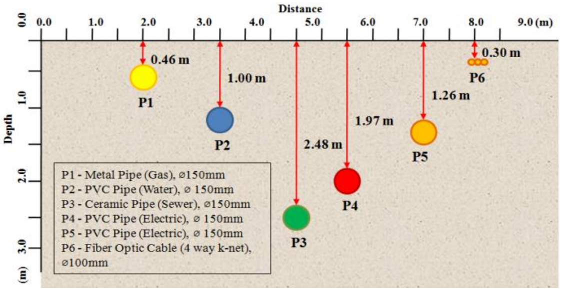

Figure 6: Test base in cross-section view

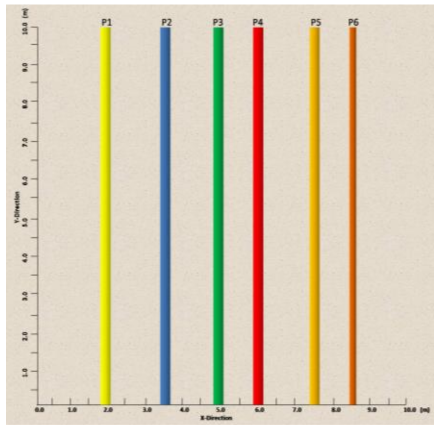

Figure 7: The arrangement of pipes and cables from top view at the test base

The x-coordinate, y-coordinate and breadth were correlating to six buried utilities buried and arrangement. Such services include ceramic sewer pipe, metal gas pipe, PVC electric cable, PVC water pipe, PVC telecommunication pipe, and optic fibre telecommunication cable.

Types of Equipment

GPRs; MALÅ GPR High Frequency (1200MHz), MALÅ Shielded 500 MHz Antenna, MALÅ Shielded 250 MHz Antenna, and Noggin Plus 250 SmartCart is used to explore the relationship between antenna frequency, their use and the maximum intensity of detection referring to the GPR frequency.

GPR Experiments: Factors Influencing GPR Dataset

Five experiments in this study carried out to determine the factors influencing GPR results. The Experiment I using MALA GPR antenna with250 MHz, 500 MHz and 1200 MHz (high frequency) used to explore the impact of the various antenna frequencies on the radargram's pixel size.

Experiment II using MALÅ Shielded 500 MHz antenna to verifies the penetration depth and the radargram quality impact of the time window. This type of antenna commonly used in the mapping of subsurface utilities because the requirement on the capability of the device as well as its antenna frequency suitable to be used to verifies the penetration depth and the radargram quality impact of the time window this field [29]. It provides a high-resolution dataset [35] and suitable to be used for both depth shallow (0 m - 2.5 m) and medium (3 m - 10 m)

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[36]. The standard subsurface utility depth ranges from 0.5 m to 5 m according to Malaysia Standard 1759:2012, Malaysia Standard 1034:1986, and Malaysia Standard 930.

Consequently, this antenna frequency used to identify subsurface pipes and cables. This experiment thus explores the effect of the time window on the extent of GPR antenna penetration and the radargram's resolution. The time window in this device ranged from 11.1 ns to 450.9 ns. As the depth of the subsurface pipes and cables at the site is unknown, a reasonable time window must choose to locate the existing subsurface pipes during the GPR scanning process.

Experiment III examines the impact of different GPR models on the radargram (using the same antenna frequency). Various manufacturers produce a different GPR model. GPR produced by multiple manufacturers is likely to have a slightly distinct performance and output in either the data format or the quality of the results. This experiment accomplished using the Shielded antenna 250 MHz from MALÅ Geoscience and Noggin 250 MHz SmartCart from Sensors & Devices Inc.

The value of the point interval determines the details of the subsurface data, that obtained by the GPR. The interval between points shows the distance between the traces [37]. The effect of the point interval on the size of the radargram pixel in Experiment IV using MALÅ Shielded 500 MHz antenna shows as 0.002 m to 1.000 m was evaluated in this experiment to demonstrate that the point interval can influence the outcomes of GPR observation.

The influence of the buried depth on the scale of the hyperbola was investigated by Experiment V using, Makmal Ujian Alat Pengesanan Utiliti Bawah Tanah, which considered as the test site. In this test site, five (5) cables with a diameter of 150 mm and one (1) wire with a diameter of 100 mm have laid underneath, with different depths.

III. RESULTS AND DISCUSSION

Experiment 1

Table II shows the impact of GPR on penetration depth and resolution of the radargram.

Table 2: Effects Of Gpr Frequency On Depth Of Penetration And Radargram Resolution

No.	**Model (GPR) and Antenna Frequency**	**Radargram**	**Depth of Penetration (m)**	**Size of Pixel (mm)**
1.	250 MHz (MALÅ Geoscience)		6.8	5.714

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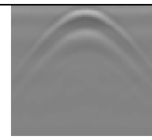
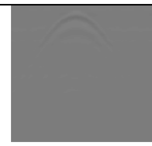
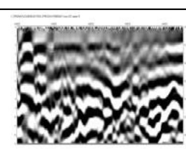
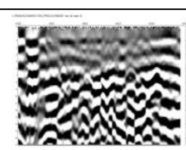
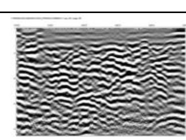
2.	500 MHz (MALÅ Geoscience)		5.2	4.505
3.	1200 MHz (MALÅ Geoscience)		2.6	3.333

The findings showed that by using the frequency of the 250 MHz antennae, the highest penetration depth was 6.8 m. The GPR with 500 MHz antenna frequency can penetrate the subsurface up to 5.2 m depth. The 1200 MHz antenna frequency, on the other side, penetrates to 2.6 m in the ground. Note that all devices have a default time window. The rate of the antenna also affects the radargram resolution. Table II indicates that the pixel size of the radargram from the 250 MHz antenna frequency GPR observation was 5.714 mm. On the other side, the 500 MHz antenna frequency generates a 4.505 mm pixel size radargram whereas the radargram pixel size provided by the 1200 MHz antenna frequency is 3.333 mm. The findings also revealed that low to medium frequency GPR is more suitable for subsurface utility detection since most utilities found at shallow to medium depths (generally between 0.5 m and 6 m). Hence, it observed from the findings that the frequencies of the antenna used influenced the depth of penetration and the radargram resolution.

Experiment II

As the time window increases, GPR signals propagate farther. Table III shows the overall results.

Table 3: The Relationship Of Time Window, Depth Of Penetration And Radargram Resolution

No.	**Time Window (ns)**	**The Radargram**	**Maximum Depth (m)**
1.	11.1		0.617
2.	20.4		1.120
3.	40.6		2.136

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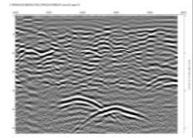
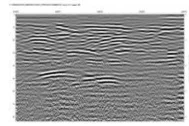
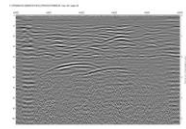
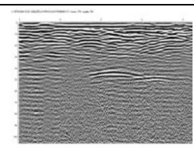
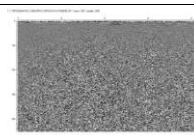
4.	60.7		3.145
5.	80.8		4.111
6.	100.9		5.286
7.	104.9		5.243
8.	362.8		18.135
9.	450.9		22.607

The findings show that time-window affects both the visualization of the radargram and the penetration depth. With the time-window value of 104.9 ns (maximum amount for short time window), the signal can reach a depth of 5.243 m and produce an excellent resolution of the radargram. The time-window value 362.8 ns (maximum amount for average time window) can go through the subsurface up to 18.135 m depth. Although it may penetrate more profound than the short time window, the radargram's resolution acquired is poor. In an excellent soil condition, the long time window with a value 450.9 ns (maximum amount for long time window) can reach the depth up to 22.607 m. However, it is not suitable to use the medium and long time window for subsurface utility detection as it creates a blurred image.

Experiment III

Variable GPR products generate distinct radargrams respect to the term of visualization and resolution. One GPR antenna may have the same frequency with the other, but the pixel size of the radargram acquired from different manufacturers of GPR is varying from each other. Table IV shows the radargram obtained from two GPR products which have the same frequency.

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Table 4: The Association Of Radargram Concerning Visualization And Pixel Size Obtained By Different Gpr Product

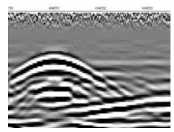
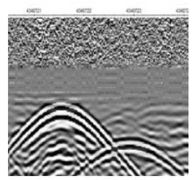
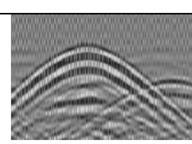
No.	GPR Model	Radargram	Size of Pixel (mm)
1.	Mala Shielded Antenna 250 from MALA Geoscience		6.579
2.	Noggin Plus 250 Smartcard from Sensors & Software Inc.		4.184

Table IV reveals that the Noggin Plus 250 SmartCarts antenna has a higher perspective than the MALÅ Shielded 250 MHz antenna. The radargram pixel size of the MALÅ Shielded 250 MHz is greater than the radargram pixel size of the Noggin Plus 250 SmartCart. The Noggin Plus 250 SmartCart has thus proven to be ultimately better in resolution than the 250 MHz MALÅ Shielded. Different GPR products provide different visualization and resolution of the radargram, although both GPR products apply the same antenna frequency.

Experiment IV

The horizontal resolutions of the radargrams defined by points interval or sometimes referred to as trace intervals, by separating two acquisitions in one row [38] and another set of an experiment to examine the effects of point interval on the quality of the radargram. Table V showed the outcomes of the test.

Table 5: The Relationship Of The Point Interval And The Radargram

No.	Pt. Interval (m)	Radargram	Interval Between Traces (m)
1.	0.002		0.002

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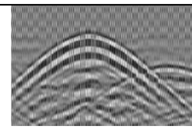
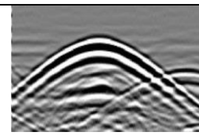
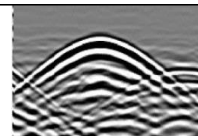
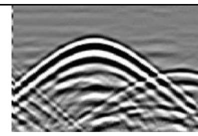
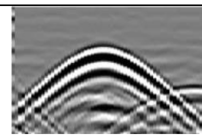
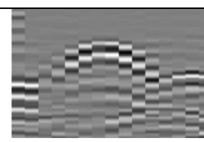
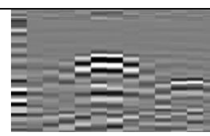
2.	0.005		0.005
3.	0.010		0.010
4.	0.020		0.020
5.	0.030		0.030
6.	0.050		0.050
7.	0.100		0.100
8.	0.200		0.200
9.	0.250		0.250
10.	0.500		0.500
11.	1.000		1.000

Point interval influenced the quality of the radargram as Table V. In the context of GPR data collection, and the point interval 0.002 implies that the information on the subsurface has collected at every 0.002 m interval. The point interval ranging from 0.010 m to 0.030 m was appropriate to be applied in the detection of subsurface utility as it generates an ambiguous and sharp radargram. The point interval of 0.050 m and above cause blurred radargram because specific data (between two traces) were missing from the signal propagation. The results

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revealed that the higher the point interval, the larger the distance between traces in the radargram and the lower the horizontal resolution obtained.

Experiment V

Six utility lines were buried underground at various positions (x-, y- and depth) within the test base differentiate as five with a diameter of 150 mm and one with a diameter of 100 mm. Fig. 8 shows the radargram of the test base obtained by MALÅ Shielded 500 MHz.

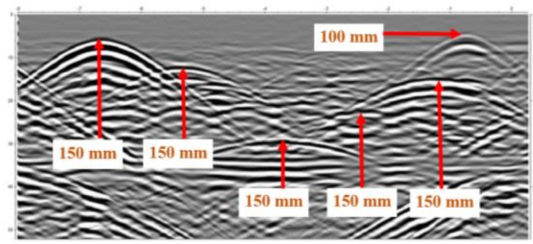

Figure 8: The radargram that represent the subsurface of the test base

Fig. 8 shows the result of GPR data collection at the test site performed using the MALÅ Shielded 500 MHz antenna. The pipes show in Fig.8 have the same size but buried in different depths and produced different hyperbola patterns, due to the time taken for the signal to propagate from the antenna and back to the receiver. These show that shorter for pipes buried in a shallow position compared to the more buried pipe.

IV. CONCLUSION

This research paper examines the factors affecting the data set acquired by GPR devices in the subsurface utility detection process. Five tests were performed in this research to verify the observations' quality and accuracy. From the experiments conducted, it can conclude that low antenna frequency (250 MHz) produces a low radargram resolution. However, the antenna frequency has its advantages as it can penetrate deeper using high-frequency. The high-frequency of antennas (1200 MHz) gives a high radargram resolution influence by shallow penetration. While using different GPR product, the various quality of radargram is generating. Besides that, the pipes and cables with the same diameter size create a different hyperbola size if buried at a different depth. The configuration of the time-window determines the limit that the GPR antenna can penetrate the subsurface. The bigger the value used for the time-window, the higher the velocity obtained, and the signals can penetrate deeper into the underground. The point interval determines the radargram's horizontal resolution. The experiment shows the narrower the point interval used, the higher the horizontal resolution of the radargram can be acquired. The general findings achieved conclude that factors such as frequency, the device setting (time window and point interval), different model GPR, and buried depth have influenced the radargram.

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