Estimation Diameter of Buried Pipe Using Principle of Ground Penetrating Radar and Electromagnetic Locator

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Abstract
A comprehensive utility map presents a complete information for users to interpret and extract the information. Its importance for underground utility database to support future infrastructure planning. However, there is not all information is available such as material, voltage, colour and diameter of pipe. The surveyor needs to observe the surrounding area of survey such as utility marker and utility box. There are lots of utility marker was missing and damage due to the road maintenance and construction work. Hence, to ensure a complete information could be presented on the map, the surveyor needs to find a method to gather the information. In this study the geophysics method was used to identify the diameter of buried pipe. The integration of geophysics principles is tested between Electromagnetic Locator (EML) and Ground penetrating Radar (GPR). The test was conducted at Jalan B2-B9, Taman Melawati, Kuala Lumpur where five points were marked on the ground as point 1, 2, 3, 4 and 5. The EML with 33kHz & 65kHz frequency have been used to locate the position and depth of buried pipe using Direct Connection technique. The GPR antenna with 700MHz frequency were tested to penetrate the subsurface up to 2.5 meter, respectively. The post processing is carried out to enhance the quality of GPR radargram profile. Thus, the velocity of hyperbola was calibrated trough curve fitting process to get the actual depth of buried pipe. The result of the study shown that the diameter of pipe is 100mm in which corresponded to the information at the pipe marker. EML and GPR is a useful method to detect the diameter of pipe, although it is required field verification and the proper selection of antenna frequency.

1. Introduction

Generally, map refer to fact, measurement, characteristic, or trait of an object of interest. A comprehensive utility map is important for infrastructure planning and figure out where the existing underground utility is located. A good utility map is also necessary to install a new route of underground utility or restructure the position of existing utilities. In the planning and execution of all types of buildings, precise knowledge of the placements and routes of the pipelines and underground cables that make up the utility networks in the area has become a requirement (Sărăcin, 2017). In order to produce a comprehensive utility map, the utility surveyor needs to provide information as much as possible to their clients. The location and classification of underground utilities is of considerable economic importance (Windsor, 2005). The plans or maps and pictures serve as essential data for guiding excavation location, defining sensitive regions holding cultural remains to avoid, situating archaeological sites in a larger environmental context, and studying human interaction with and adaptation to historical landscapes. (Kvamme, 2003). Thus, the information such as positions, depth and types of underground utilities need to be shown completely in underground utility map.

A good underground utility map contains the information such as types of utilities, depth, location, route, diameter, colour, material, and voltage of buried pipe. Those information could be obtain from detection work and utility provider and some of the information could be obtain from the utility marker were located nearest to the road shoulder. However, there are lots of utility marker when missing and damage due to the road maintenance and construction work. Hence, it is quite difficult for utility surveyor to gather the information such as diameter of pipe in utility map. Classic technology based on excavation, 30-year-old maps with more or less precise pipeline routes and incorrect measurements causes incorrect information and major problems with underground utility mapping (Petrovački and Ristić, 2005). In this study, the geophysics method was used to integrate Ground Penetrating Radar and Electromagnetic Locator in order to provide information of buried pipe. Due to the success of geophysical approaches in delivering rapid subsurface information, such as locating buried utilities, forecasting their depth and geometry, geophysical applications in the context of urban planning are becoming more common in the literature (Poluha et al., 2017). Therefore, the integration of geophysics principle of GPR and EML were tested to identify the estimation of diameter of buried pipe.

2. Principles of GPR and EML

Technology is developing rapidly, so there are a lot of equipment for the underground utility detection today. The electromagnetic method is used widely for detecting the location of underground utilities such as GPR and EML. The electromagnetic spectrum is vast, and a small section of it can be utilised to detect utilities (Sterling et al., 2009). GPR and EML are one of the geophysical methods that are widely used today. GPR method works to detect both of materials of underground utilities either metallic or non-metallic meanwhile EML method is to detect only conductive utilities such as metal pipe, power cable and telecom cable. Both methods are well known for being a non-destructive method. These approaches have the advantage of requiring no physical contact with the surface during measurement, in contrast to mechanical wave methods, which need substantially longer survey periods (Lai, 2021). However, each equipment is complementary to each other in order to detect and locate the metallic and non-metallic utilities.

2.1 Ground Penetrating Radar

GPR is a device which emits and receives electromagnetic wave penetrating materials like concrete, soil, asphalt, and others. The GPR approach is based on the idea of tracking the propagation route of generated EM waves through the examined medium. The GPR method involves measuring the time it takes for electromagnetic (radar) waves to be generated at a surface antenna, transmitted to depth, reflected from buried discontinuities, and finally received and recorded at the surface (Conyers, 2018). The propagation of electromagnetic waves is affected by the electrical and magnetic properties of a material or medium (Apaydın et la., 2022). The electromagnetic pulse is sent into the ground via the antenna. A portion of the energy is reflected when an interface of between materials of different dielectric constant is encountered. Three major features of dielectric materials influence how a wave propagates through the medium: permittivity (ε), conductivity (s), and magnetic permeability (Jol, 2009). The dielectric constant is referred to the level of soil moisture. Image reconstruction of the reflected wave amplitude by signal processing and imaging technique. The depth of underground utilities is measured from the top of materials to the surface Because of the way hyperbolas are formed, it is the shortest distance, the top of the hyperbola, that indicates the position of the target in the ground for discrete objects (Erica, 2017).

2.2 Electromagnetic Locator

EML is very famous and common tools that was used widely around Malaysia especially for underground utility detection work. Pipe and cable locators are the most common instruments for detecting and tracing underground utilities (Sterling, 2009). It is capable to detect metallic utilities with ±5% accuracy compared to the real depth. Assuming a long straight isolated target line, a visual output device that can be resolved to within 1 percent of full scale and vertical alignment of the antenna, a vertical aerial can resolve position to better than ±5 percent of depth, a single horizontal aerial to ±10 percent of depth and twin horizontal aerials to ±5 percent of depth of the line (Iaccarino, 2018). The EML do not trace the cables or pipes, but it detects the electromagnetic field which is produced around any conductive linear features. The receiver will respond to the signal that flowing and travelling from the transmitter to the conductive cable or pipe.

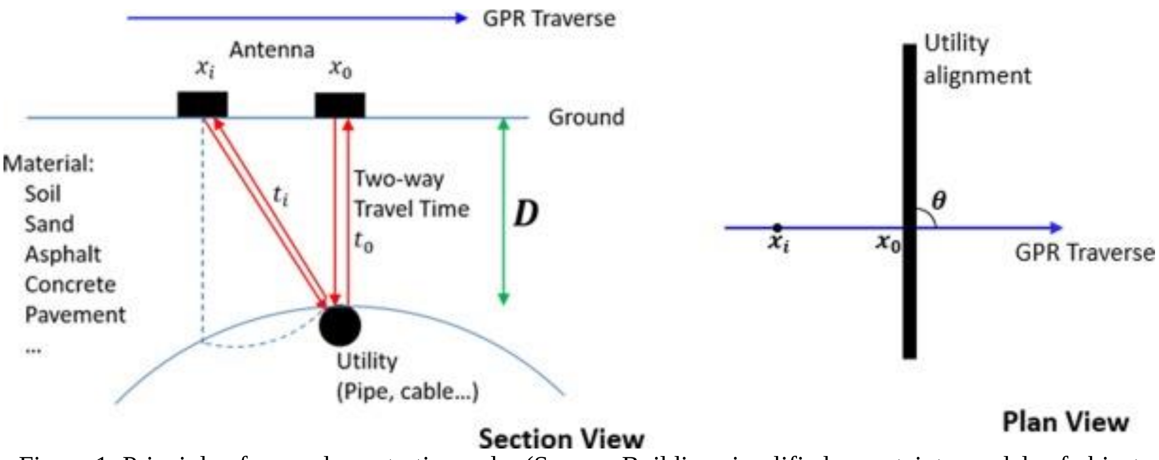

Figure 1: Principle of ground penetrating radar (Source: Building simplified uncertainty models of object depth measurement by ground penetrating radar, Xie, F. and Lai, W. W. L., (2021)

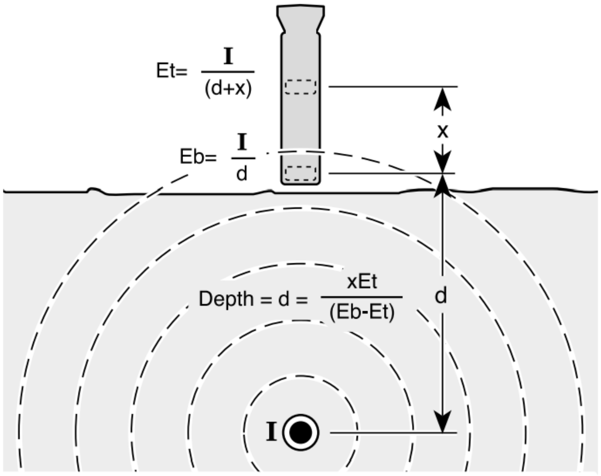

Figure 2: Principle of electromagnetic locator (Source: The theory of buried cable and pipe location by Radio detection Ltd, (2017)

The magnetic field distribution on the earth's surface generated by signalling current flowing through the cables installed inside the ducts is the key technology for detecting a cable burial location (Kijima and Hattori, 2016). The depth of utility is measured accurately when the receiver of EML is located directly over the utilities. The cable's position profile can be determined by studying the magnetic field pattern of the electrical transmission (Kijima and Hattori, 2016). Depth of utility is measured to the center of the signal (Figure 2).

2.3 Transmission of Velocity

The depth of hyperbola could be defined by identify the velocity value. The transmission of velocity into the ground is varying at certain area because of different value of dielectric constant. Hence, to identify the actual depth, the velocity of each hyperbola needs to be calibrated trough curve fitting process. Then, the actual depth could be defined through the formula (Buynevich and FitzGerald, 2017):

$$D = \frac{1}{2}(v\,t)$$

Equation 1

D = Corrected depth of hyperbola from surface to the top of pipe
V = Actual Velocity
t = Signal travel time

2.4 Estimation the Diameter of Buried Pipe

In general, pipes are designed with a cylindrical shape which carries various size and diameters. The diameter of pipe could be estimated by identify the radius of the pipe.

Theoretically, the depth of the utility which detected by GPR is measured from the ground surface to the top of the utility meanwhile the depth of the utility that detected by EML is measured from the ground surface to the center of the utility. Therefore, the radius of the pipe needs to be identified to define the diameter of the buried pipe.

Radius of Pipes : *Rp*
Depth Measured by GPR : *DGPR*
Depth Measured by EML : *DEML*

$$Rp = DGPR - DEML$$

Equation 2

Diameter of Buried Pipes:

$$Øp = Rp \times 2$$

Equation 3

Based on the Figure 3, the diameter of buried pipe could be determined by define the radius of the pipe. The radius of the pipe could be calculated by minus the depth of pipe (Equation 2) that measured by EML and GPR. Thus, the size of the utility could be identified (Equation 3) and checked with the information that have been obtained during reconnaissance stage.

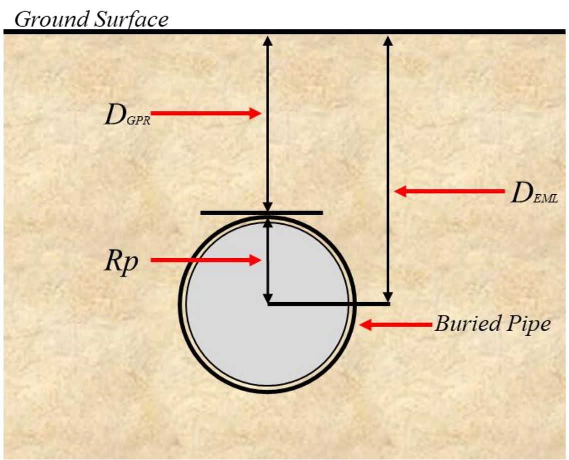

Figure 3: Dimension of Utility Depth Measured by EML and GPR

3. Materials and Methods

In this study, it emphasizes the principle of utility detection equipment application to identify the diameter of the buried pipe. The methodology is divided into three stages in which involve the preparation stage, data acquisition and result analysis. The first stage is planning and reconnaissance stage where it is involving the step of identifying the location and selecting the types of utility that suitable to be located and scanned. The next stage is implementing the data acquisition such as detection work by EML to locate the position of the buried pipe and scanning survey by GPR to generate the radargram. The final stage is data analysis which involving the GPR post processing by using ReflexW software and analysing the result of EML to define the radius and diameter of the buried pipe (Figure 4).

3.1 Planning and Reconnaissance

Planning and reconnaissance are carried out to identify the location and utility information that suitable for this study. This stage is to determine the equipment and method that will be used to comply the objective of this study.

3.1.1 Study area

The location of this study was conducted at Jalan B2-B9, Taman Melawati, Kuala Lumpur (Figure 5).

3.1.2 Utility information identification

In this study, the water pipe was selected as the object of the study because of the shape of water pipe is cylindrical shape and it has a various diameter. In addition, this utility provides the information of the material, diameter and information of stakeholder could be obtain at the utility markers were located at the road shoulder. It is recommended that for georadar mapping, other information sources be used to obtain a set of data from existing maps and plans until a visual localization of networks, their depth, diameter, and direction of advancement through manholes is achieved (Sărăcin, 2017) (Figure 6).

3.1.3 Equipment

The equipment used in this study is Ground Penetrating Radar (GPR) and Electromagnetic Locator (EML). They were Leica DS2000 with 700MHz frequency (Figure 7a) and RD8000 with multi-channel frequency (Figure 7b).

3.2 Electromagnetic Locator Detection

The position and depth of utility is detected using Direct Connection technique. In 1998, the 3M Telecom Systems Division stated that connecting directly to the cable or pipe you want to trace (power cables only if they can be deenergized) is the most accurate method of cable locating. Figure 8 below show the setup of Direct Connection technique but in this study the cable connection (1) has been connected to the fire hydrant chamber.

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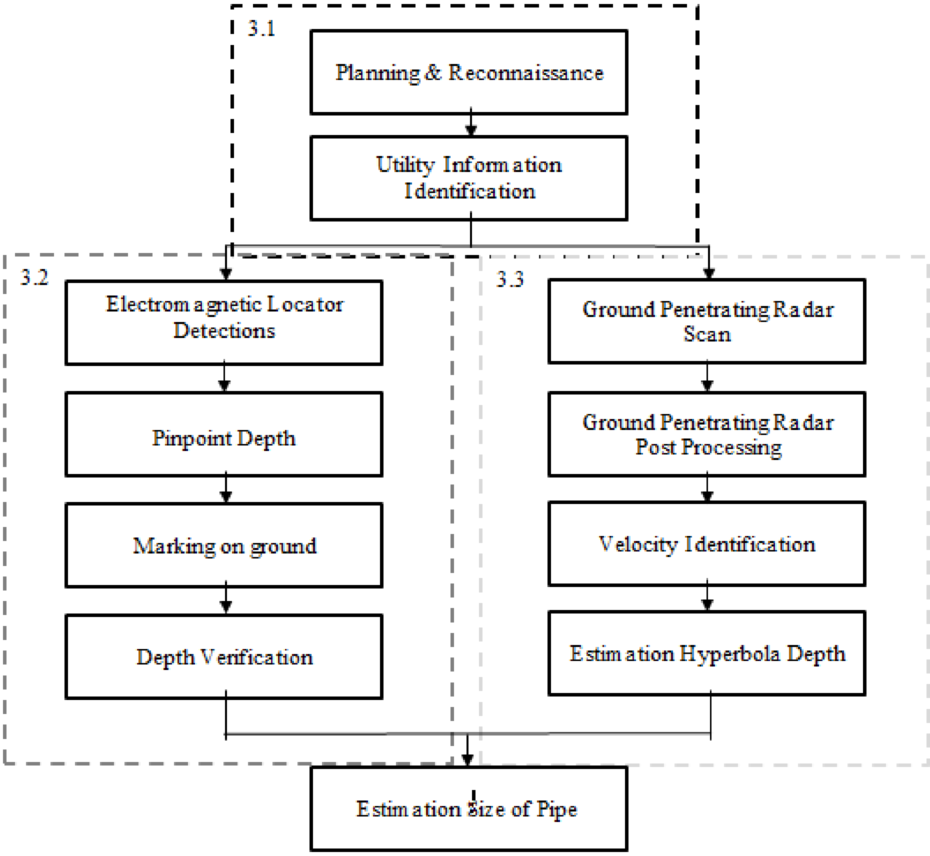


Figure 4: Methodology of the study

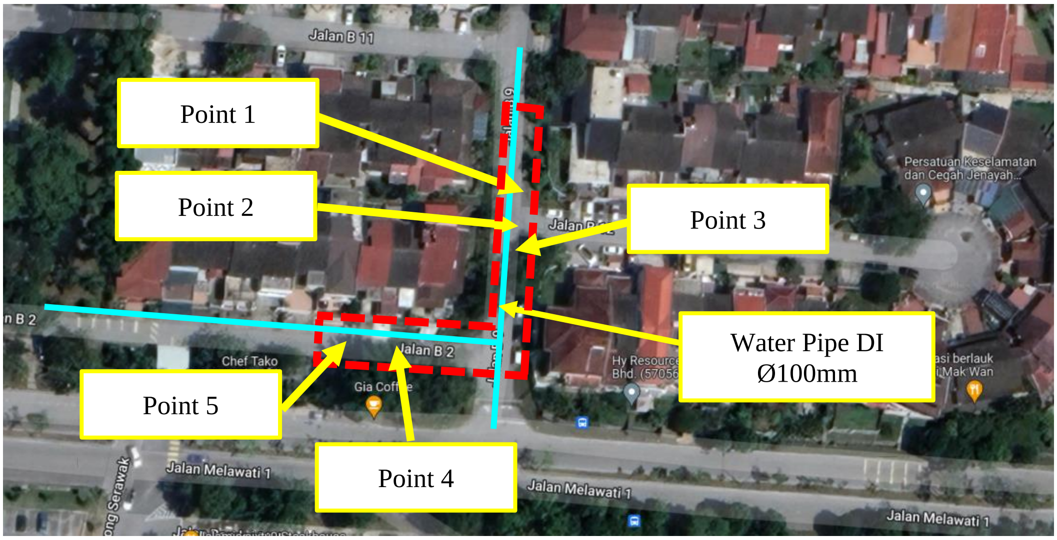


Figure 5: Test site at Jalan B2-B9, Taman Melawati, Kuala Lumpur (Source: Google Map)

Figure 6: Pipe Marker at Jalan B2-B9, Taman Melwati, Kuala Lumpur. The size of pipe is 100mm with ductile ion material

a) b)

Figure 7: a) Leica DS2000, (Source: https://survey.crkennedy.com. au/products/LG847111), b) RD8000, (Source: https://www.test-equipment.com.au/radiodetection-rd8100-precision-service-and-utility-rf-marker-locator/).

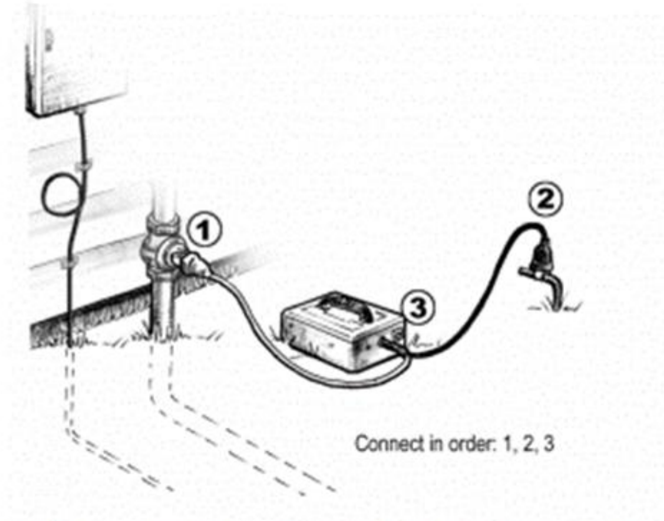


Figure 8: Direct connection technique using electromagnetic locator, (Source: Setting up the transmitter for Conductive Locating – Pipehorn Locating Technology)

The 33kHz and 65kHz frequency were used to transmit the signal flow along the buried pipeline with 20mA of milliampere. Each point of detection is marked as number 1, 2, 3, 4 and 5 on the ground where's the point will be scan by GPR.

3.2.1 Detection mode & frequency setup

The Peak Mode is used to detect the buried water pipe. This mode was used because it's providing a maximum response over the line of underground utility (3M Telecom Systems Division, 1998). Hence, it's good for tracing and pinpoint the line of utility especially in congested areas. In this study, the frequency 33kHz and 65kHz were used to locate the buried water pipe because it gives more stable signal flow along the pipe with minimum distortion.

3.2.2 EML depth verification

The values of depth that have been located by EML is verified through 70% Triangulation Depth method. By using Peak Mode, the EML is setup at 100% gain and located at the point that have been marked on the ground. The receiver was move to the other side without changed the gain setting until the gain reduce to 70% and the position is marked. After that, the receiver of EML was move to another side until the gain reduce to 70% and the position is marked. If the distance measured between both side is equal to the detection depth, so the depth that have been detected is acceptable.

3.3 Ground Penetrating Radar Scan

The scanning of GPR was carried out for every point that have been marked and detected by EML. The scanned is needed to acquire the information of buried water pipe depth which measured from the ground to the top water pipe.

3.3.1 Scanning setup

In this study, the GPR were setup as the following setting:

Antenna Frequency : 700MHz
Time Sweep 50 ns
Estimation Scanning Depth: 2.5 m
Velocity : 0.1 m/ns (assuming dry soil)
Radargram Colour: Grey Scale
Antenna Couple: Ground Coupled

3.3.2 Post processing

Basic processing and filtering of GPR data was applied by using ReflexW software. As mentioned in para 3.3.1 the velocity 0.1m/ns was used as transmission signal into the ground by assuming that the soil is dry. It was necessary to have a measurement of the transmission velocity and, in many cases, an indication of its variability within any given site in order to fully utilise the accuracy of depth readings when using a GPR. Carrick, 2017). Therefore, the velocity of each radargram profile need to be calibrated because each velocity profile entirely depends on the site conditions. The curve fitting process were carried out to define the calibrated velocity (Figure 9). Time is converted to depth using velocity profile estimates, which results in a superior profile image (Switzer, 2020).

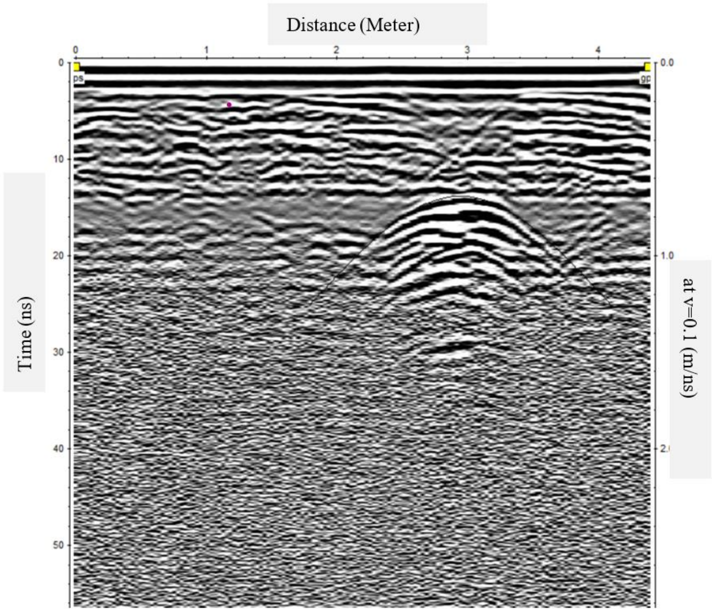
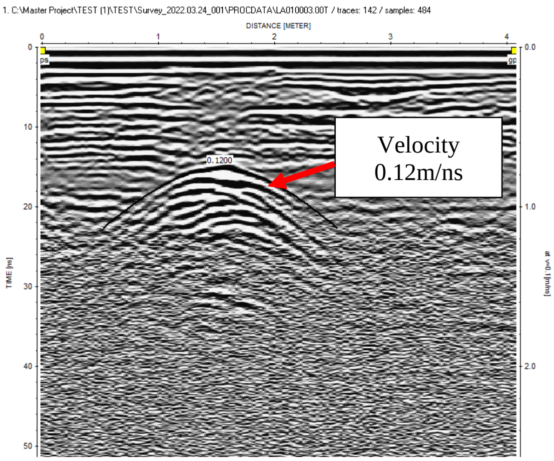


Figure 9: Velocity calibration trough curve fitting process

4. Results and Discussion

EML provided instant result in which shown on the receiver screen based on the pinpoint process while GPR generated radargram profiles based on signal propagation and subterranean material parameters. The utilities or anomalies that scanned by GPR is shown in the form of a hyperbola on the radargram. The Figures 10 – 14 shows the result of the study that have been caried out by using EML and GPR at Jalan B2 – B9, Taman Melawati. The radargram in B-Scan that has been post processed using ReflexW software is the outcome of GPR scanning. Because it is a synthetic radargram, the diffraction hyperbolas of the objects are easily identified in Figures 10 – 14(a). After acquisition, frequency filtering and reflection amplification techniques can sometimes be used to enhance some very low amplitude reflections in order to make them more visible, but all radar energy is lost at a certain depth and in certain materials in all ground conditions (Conyers, 2011). The radargram profiles shown hyperbola that represent the location of the buried pipe. Each radargram profiles produced different conditions after post processing and the quantitative comparison can be made for each buried pipe. The velocity profile of each point is calibrated trough curve fitting process. Its important to get the calibrated velocity because it will affect the actual depth of the buried pipe. After velocities have been calibrated for each target by means of hyperbolic adjustments, the layers are defined considering the tops of the pipe located at different depths and laterally proximate. From the radargram profile, the time sweep of GPR scan is identified where the signal travel from the antenna into the ground and when the signal hit or meet the initial part of the buried pipes. Apart from that, the actual depth of the buried pipe could be calculated by using the Equation 1.

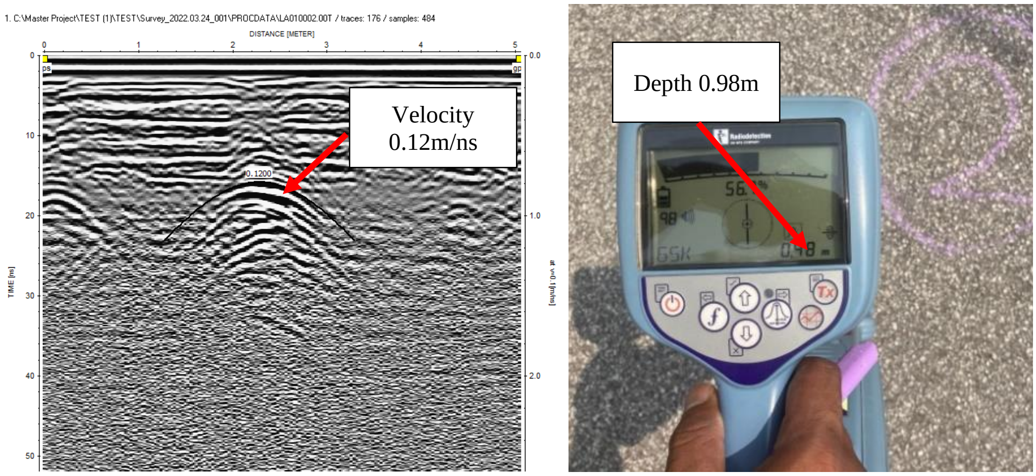
From the Figures 10 – 12(b) it shows the locating result that acquired by EML where the frequency used for Point 1, 2 and 3 is 33kHz with 20mA. For the Point 4 and 5, the Figures 13 – 14(b) shows the EML locating was using 65kHz with 20mA. This is because the pipe at Jalan B2 is connected to the main pipe at Jalan B9 where it might cause the unstable signal flow along the pipe. Thus, the frequency was increased to 65kHz to transmit the stable signal flow along the buried pipe at Jalan B2. The depth of utility is defined when the receiver of EML pinpoint the signal above the buried pipe. The mode Peak is used at point 1, 2 and 3 to pinpoint the position and depth of the buried pipe. While the mode Peak and Null is used to pinpoint the position and depth of the pipe at point 4 & 5. This mode was used because This mode was used because of the difficulty to pinpoint the position of the pipe. The result of the locating pipe was verified trough 70% triangulation depth process to ensure the depth and position is correct.



(a)

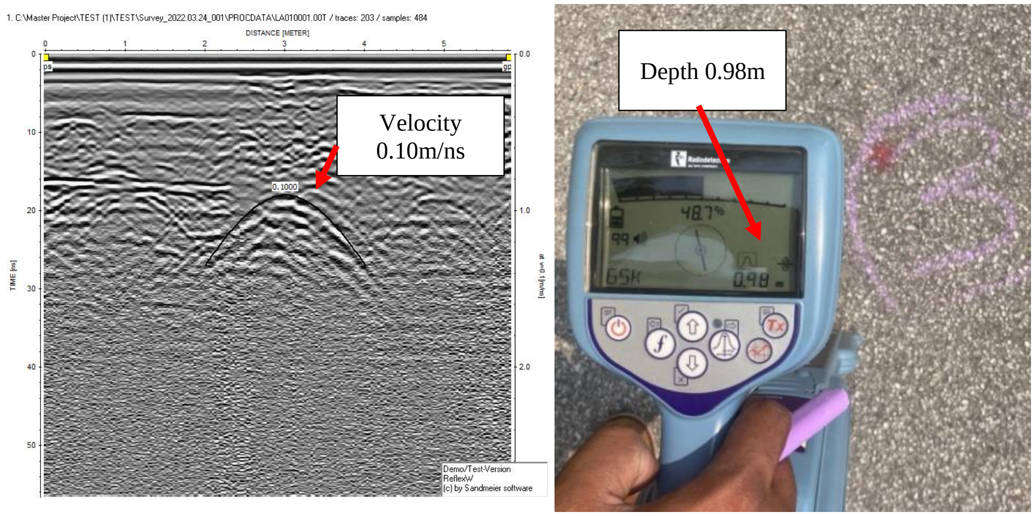
(b)

Figure 10: (a) Radargram of GPR in B-Scan, (b) EML detection result at Point 1



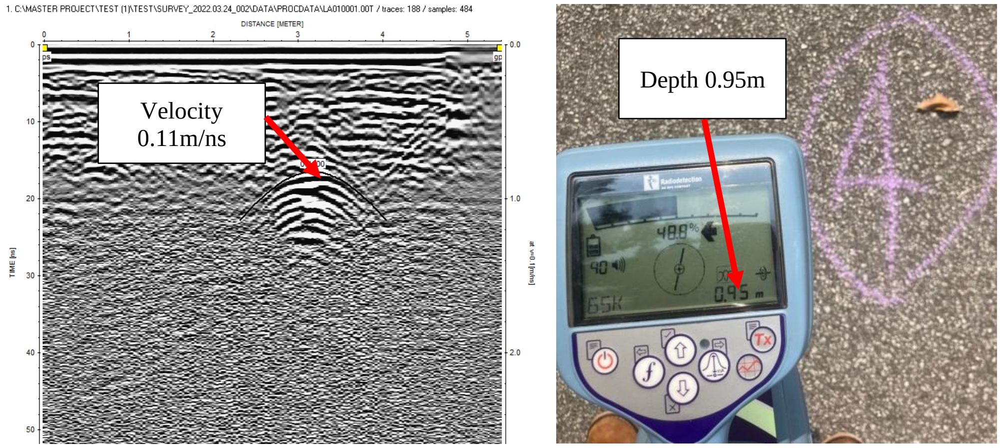
(a) (b)

Figure 11: (a) Radargram of GPR in B-Scan, (b) EML detection result at Point 2



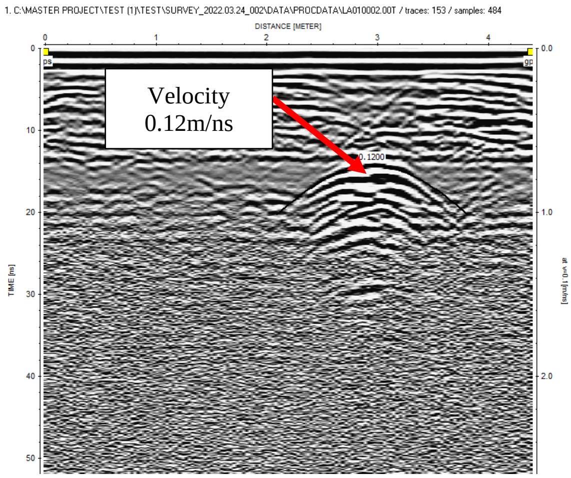
(a) (b)

Figure 12: (a) Radargram of GPR in B-Scan, (b) EML detection result at Point 3

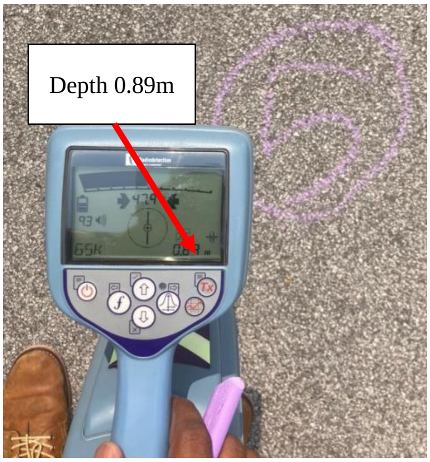


(a) (b)

Figure 13: (a) Radargram of GPR in B-Scan, (b) EML detection result at Point 4



(a)



(b)

Figure 14: (a) Radargram of GPR in B-Scan, (b) EML detection result at Point 5

Table 1: Actual depth of buried pipe

	Velocity (m/ns)	Time Sweep (ns)	Actual Depth (m)
Point 1	0.12	15.605	0.94
Point 2	0.12	15.511	0.93
Point 3	0.10	18.595	0.93
Point 4	0.11	16.539	0.90
Point 5	0.12	14.110	0.84

Table 2: Estimation size of pipe

	Depth of EML (m)	Depth of GPR (m)	Radius of Pipe (m)	Estimation Diameter of Pipe (Ø mm)
Point 1	0.99	0.94	0.05	100
Point 2	0.98	0.93	0.05	100
Point 3	0.98	0.93	0.05	100
Point 4	0.95	0.90	0.05	100
Point 5	0.89	0.84	0.05	100

4.1 Actual Depth by GPR Scan

From the Table 1, the velocity value was calibrated trough curve fitting process by using ReflexW software. A few scanned points were carried with different value of the velocity because of the dielectric constant factor. The time sweep is referred to the signal travel time from the GPR antenna into the ground. The values of the signal travel time are different because of the different depth and position of the buried pipe. Based on the Table 1, its shows the actual depth of buried water pipe that have been scanned by GPR Leica DS2000. The actual depth is calculated by using the Equation 1. From the result, the average depth of the buried pipe is around 0.92m for Point 1,2,3 and 4 except for Point 5 which is 0.84m below the ground surface. The result of the actual depth might be different in range of ±0.02m because of the data interpretation during curve fitting process because there is a small range of values which will fit the same hyperbola position.

Table 2 shows the comparison result of the depth measured by EML and GPR to define the radius of buried pipe. The radius of the pipe was calculated by using the Equation 2. The result shown that the radius of the pipe for each detection point is 0.05meter.

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Thus, the diameter of buried pipe could be define using Equation 3 as below;

Radius, Rp = 0.05m
Diameter of pipe, $Øp$ = 0.05m x 2
Estimation diameter of buried pipe = Ø 100mm

Based on the result, it could be concluded that the diameter of the buried pipe in this study is 100mm. Therefore, the diameter of the buried pipe was corresponded to the information on the water marker at Jalan B2 – B9, Taman Melawati. Despite the fact that this is a relatively frequent way of determining diameter, it has limitations. The GPR data must contain sufficiently clear hyperbola. The GPR radargrams that do not present a clear hyperbola or too much noise in the data can make it impossible to caried out the curve fitting process where it might affect to the actual depth of buried pipe. The lack of skills to carry out the curve fitting process will affect to an appropriate velocity value. In most cases, a small range of numbers will fit the same hyperbola outline. Besides that, the accuracy of EML locating should be noted that there was distortion of magnetic field especially in the congested area. The distortion of magnetic field usually disrupts the confidence of the surveyor to operate this equipment. However, while no theoretical qualifications or skills are required to successfully use EML equipment, having a basic understanding of what is happening in this invisible world of magnetic fields will help to boost surveyor confidence.

5. Conclusion

In this study, the diameter of buried pipe was identified. The diameter pipe Ø100mm is corresponds to the information displayed on the pipe marker. Its shows that the integration of the principles EML and GPR could be applied to identify the diameter of the buried pipe. From EML method, the readings of locating need to be measured repeatedly to get the average values of depth. Validation of depth need to be caried out to ensure the utility surveyor more confident toward on the result of detection. The result of B-Scan from GPR provide a good radargram for data interpretation purpose but it requires a post-processing to calibrate the values of velocity. Thus, the actual depth and diameter of pipe could be determined precisely. Although this method can be proven through this study, remember that the post processing of GPR and data validation of EML detection were subjective and the calculation is based on an estimate and requires prior knowledge of pipe contents.

Besides that, the tests were performed at small area and focus on one type of material pipe which is Ductile Ion. There are various types of pipe materials such as Stainless Steel, Mild Steel, Copper Polybutylene, High-Density Polyethylene (HDPE), Acrylonitrile Butadiene Styrene (ABS), Glass Reinforced Polyester (GRP), Reinforced Concrete (RC) and Polyvinyl Chloride (PVC). Based on the EML principle's, it can only detect conductive pipes. Thus, it should be remembered that not all the pipe types could be tested by using this integration method to identify the diameter of pipe. Furthermore, in this study assumes that the pipe is completely full of the water, and it is not always the case. Therefore, it might be probably producing a different effect of data especially on GPR radargram profile.

Other than that, every GPR antenna varying multi frequency which effected to the minimum target size. In this study, the 700MHz antenna were used where the minimum target size detectable is 0.014m (14mm). The suitable antenna frequency needs to be considered when carried out the GPR scanning. High frequencies of GPR are good for producing high resolution radargrams which aid for data interpretation. However, the practical applicability in this study is not extended to all aspects such as materials of pipe and frequency of GPR antenna that might be produce different result of the estimation diameter of pipe.

Other environmental conditions, such as the surface material and the complex underground, as well as detection settings, such as the GPR positioning method, play a role in data interpretation, and the applicability of future learning frameworks will be investigated in more complex cases in the future. Nevertheless, further research is planned in a few aspects. First, the test could be carried out at Utility Lab Test at Department of Survey and Mapping (JUPEM) because the depth and size of the utility have been proven. Besides that, the research also could be test to the other type of pipe material. Finally, the only way to get an exact diameter of the buried pipe is carried out the trial pit test but this method is costly and destructive the environment.

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