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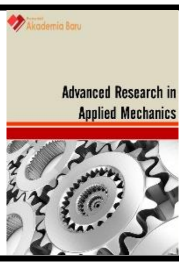

Undergrounds Water Pipe Mapping using Ground Penetrating Radar and Global Positioning System

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ABSTRACT

A complete water pipe plan with the position and depth of the water pipe from ground surface is really important for future maintenance, upgrading and construction. A non-destructive technique, Ground Penetrating Radar (GPR) with 400 MHz frequency antenna and Radan 7 software from GSSI can be utilised to detect the buried water pipes under concrete and asphalt pavement and dry clay at more than 1 m from the ground and with the support from global positioning system (GPS). Site tests where the depth of the pipes are accessible from the ground (concrete and asphalt pavements and dry clay) were done to determine the accuracy of the GPR signal analysis. Results shows that the depth of embedded water pipe obtained using GPR under concrete pavement is 1.55 m while the actual depth is 1.64 m with 9 cm or 5% difference and is 0.96 m (GPR) and 1 m (actual) with 4 cm or 4% difference under dry clay. Both results shows that GPR method is accurate with negligible error. The depth of embedded water pipe under asphalt pavement is later determined as 1.2 m. Standard Guideline for Underground Utility Mapping by Department of Survey and Mapping Malaysia (JUPEM) required accuracy of 10 cm (in vertical and horizontal direction) of the utilities mapped to be classified as Quality Level A. Based on results of these site surveys, analysis of GPR electromagnetic waves to map underground utilities is proposed when Quality Level A is required and mapping plan of underground pipe can be produced with help of GPS.

Keywords:
Ground penetrating radar, underground water pipe, 400 MHz frequency antenna

1. Introduction

One of the main issues in the management of construction project during the construction stage was the problem of coordination [11]. The absence of complete information about the position and depth of the underground utility makes it difficult for the upgrades and maintenance works of to be done. Each year, approximately RM 12.9 billion was spent by the Malaysian Government, which is the cost of losses due to the failure of excavations for utilities maintenance. Therefore, the

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underground utility plan must be updated so the bad side effects such as loss of cost or even worst loss of lives can be prevented during the work of upgrades and utilities maintenance work.

Mapping the underground utilities with a non-destructive technique (NDT) is needed to retrieve the location of underground pipelines, in order to update urban cadastral databases and to contribute to space saving and to a wise use of land resources when planning for new networks [3]. Moreover, such an inspection is an opportunity to identify buried pipes and checking their operating status [8].

Currently, the ground-penetrating radar (GPR) method has gained increasing importance as the dominant technology for location surveys in civil engineering works. It is often a more effective tool in the study of underground structures than other geophysical methods [13]. GPR has been widely used in detecting and locating underground utilities due to its many advantages such as: fast data acquisition, cost effectiveness for mapping large areas, better results compared to other non-destructive technologies and because it provides high resolution imagery, for improved interpretation [9,10,12,5,7].

Three basic principles are applied in modern GPR which are tomography, reflection of wave amplitude and velocity of electromagnetic waves. In terms of tomography principle, two-dimension data will be collected at the investigation sites using GPR then it will be analyze using computer software called Radan 7. For the principle of reflection wave amplitude, dielectric constant and conductivity of medium are really important. The velocity of GPR electromagnetic waves depends on dielectric of the medium below the GPR antenna. Reflections of electromagnetic waves are generated because of the difference in dielectric constant of underground material with the ground surface dielectric constant. The time travelled by the electromagnetic waves when they leave the transmitter antenna to medium and reflected back to receiver antenna on the surface indicates the depth of the reflection point and electrical properties of the media [6]. Table 1 shows the dielectric constant for different mediums. Air has the lowest dielectric constant value which is 1 and water has the highest dielectric value which is 81. The higher the dielectric value the harder for the electromagnetic wave to be detected by the GPR antenna.

Table 1
Type of medium or materials and their dielectric constant value. Source: ASTM D6432-11

Type of Medium or Materials	Dielectric Constant Value
Air	1
Water	81
Sea Water	70
Dry Soil	4-6
Moist Soil	25
Mud	10
Clay	8-12
Concrete	5-10
Asphalt	3-5
Lime Stone	7-9
Granit	5
PVC	3

GPR's operations in the 10–100 MHz range are suitable for imaging deep foundations on the tens of meter scale; GPR's in the 100–1000 MHz are used to investigate road pavements, tunnel liners and utilities on the meter scale, and GPR's in the 1000–5000 MHz range are used for tunnel liners and building structures assessment on the centimetre scale. As in seismic geophysical techniques, there is a trade-off between frequency and structural resolution. The high-frequency waves produce higher resolution models at shallow depth only, whereas low frequency waves produce lower resolution models that may be located at greater depth. The choice of appropriate antenna is a target dependent on the projects goal. Table 2 show the GPR antenna frequencies with their application and maximum penetrating depth.

Table 2
Antenna frequency, application and maximum penetrating depth.
Source: ASTM D6432-99(2005)

Antenna Frequency	Application	Maximum Penetrating Depth
1.6 GHz	Concrete structure, road, bridge	0.5 m
900 MHz	Concrete, shallow soil	1 m
400 MHz	Utilities	3 m
200 MHz	Geology	8 m
100 MHz	Geology	20 m

The GPR uses high-frequency-pulsed EM waves (from 10 to 3000 MHz) to acquire subsurface information. Energy is propagated downward into the ground from a transmitting antenna and is reflected back to a receiving antenna from subsurface boundaries between media possessing different EM properties. The reflected signals are recorded to produce a scan or trace of radar data. Typically, scans obtained as the antenna(s) are moved over the ground surface are placed side by side to produce a radar profile. Figure 1 shows the GPR's operation.

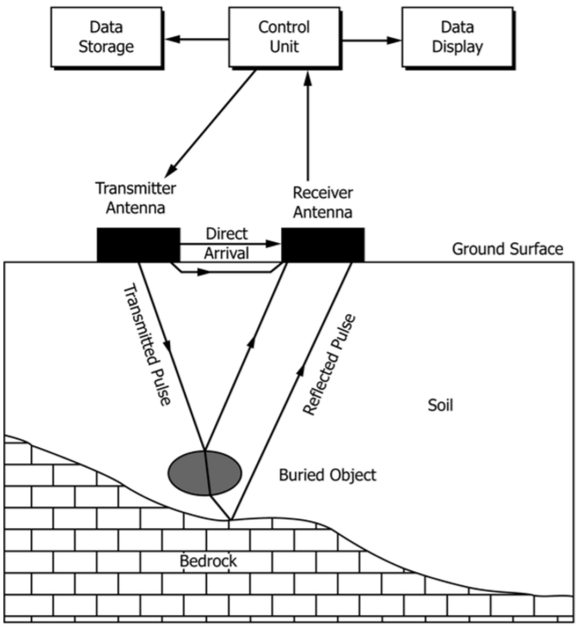


Fig. 1. Principle of GPR electromagnetic wave propagation in medium, **Source: ASTM D6432-11**

The raw data are being collected at the sites using GPR, and later transferred to *Radan 7* software for further analysis to obtain the the two-way travel time of electromagnetic waves (T) and the velocity of the electromagnetic waves (V_m). The depth of penetration (D) then can be determined by using the formula

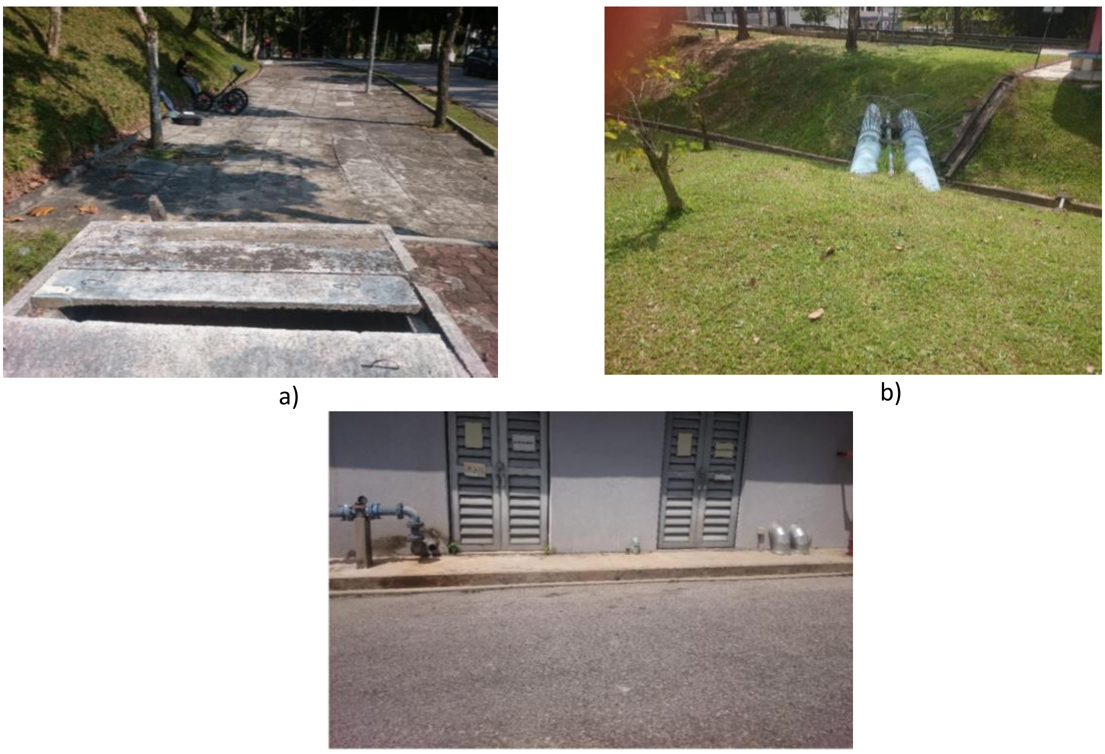
$$D = \frac{T \times V_m}{2} \tag{1}$$

The selected area is around the university campus which had been built some 50 years ago and the complete underground utilities plan are not available which could make the upgrading and maintenance of underground utilities problematic. This study is to verify the accuracy of GPR in locating underground water pipes under two surfaces, which are concrete pavement and soil, where the actual depth of the pipes are accessible to be measured for comparison (Figure 2a), b)). Based on the results, location underground water pipe elsewhere can be determined (Figure 2c)).

2. Methodology

2.1 Field Data Acquisition

SIR-3000 system from GSSI and antenna with 400 MHz (maximum penetrating depth up to 3 m) were used for collecting data at the sites. GSSI cart was used to collect the data in distance mode with time range of 50 ns and sampling rate of 512 sample per trace, 50 scans per meter, and 100 scans per second. Low cut filter of 800 MHz and high cut filter 200 MHz were used to collect data. The dielectric value of concrete, soil and asphalt medium are chosen as 8, 3 and 5 respectively. All input values are based on SIR-3000 System Manual provided by GSSI. The position of the selected location (coordinates of latitude and longitude) were marked and recorded using Global Positioning System (GPS). Figure 3 shows the flow chart of site investigation using GPR.



c)

Fig. 2. Different medium of buried pipes a) concrete b) soil and c) asphalt

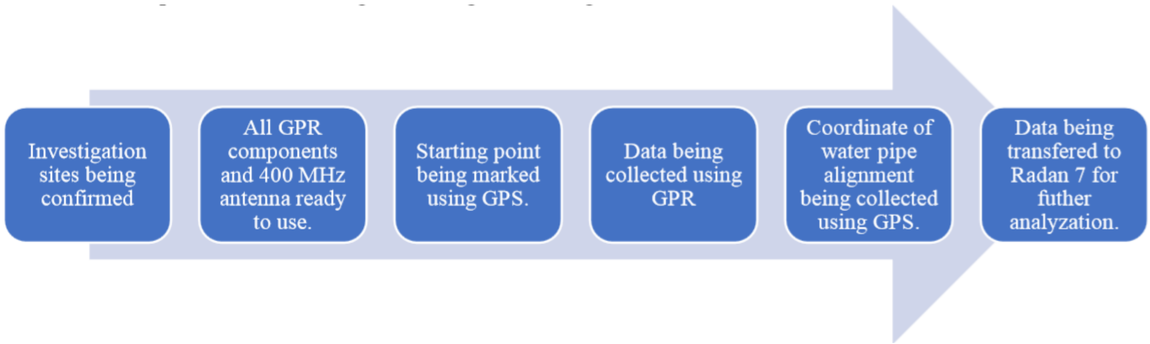


Fig. 3. Flow chart of site investigation using GPR

2.2 Data Processing

Analysis of data is done using Radan 7 software. The data collected are considered as raw data and need to be analyze and filter to determine the depth of the water pipe. The processes involve time zero correction (adjustment) for removing the delay time from the first reflection in order to correct the effect of the distance between the transmitter (T) and the receiver (R) antenna; background removal filter for removing the average values across all traces on the horizontal axis (horizontal banding or horizontal noise); distance normalization which is use when collected data are not consistent and lastly, Kirchhoff migration to enhance the hyperbola to determine the clearer location (depth of the water pipe) (Figure 4).

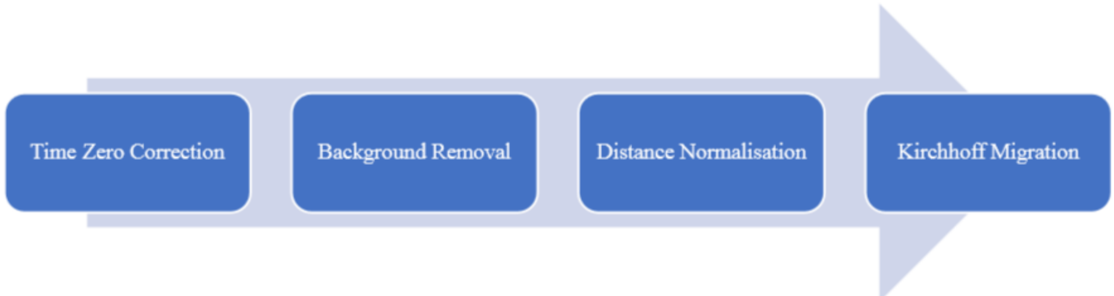


Fig. 4. Analyzing and filtering process in Radan 7

The two parameters measured are the T of the electromagnetic wave and V_m of the top hyperbola at both verification sites (concrete and soil surfaces), and testing site with asphalt surface using input dielectric value of 5 following Table 1. The T and V_m are included in Eq. 1 to determine the depth of the embedded water pipe.

3. Results and Discussion

Figure 5 a) - e) shows the images of each process as described in Figure 4 for embedded pipe under concrete and Figure 6 a) - e) shows images for soil medium. The T and V_m of wave to reach pipe under concrete surface are 36.56 ns and 0.085 m/ns, respectively and from Eq. 1, the depth of embedded water pipe (D) at that location is 1.55 m. The actual depth of embedded water pipe at that location is measured as 1.64 m with difference of 9 cm or 5%. Based on Figure 6, the T and V_m of wave to reach pipe under clay surface are 20.04 ns and 0.096 m/ns, respectively and consequently, D is 0.96 m. The actual depth of the embedded water pipe at that location is 1 m, with difference of 4 cm or 4%.

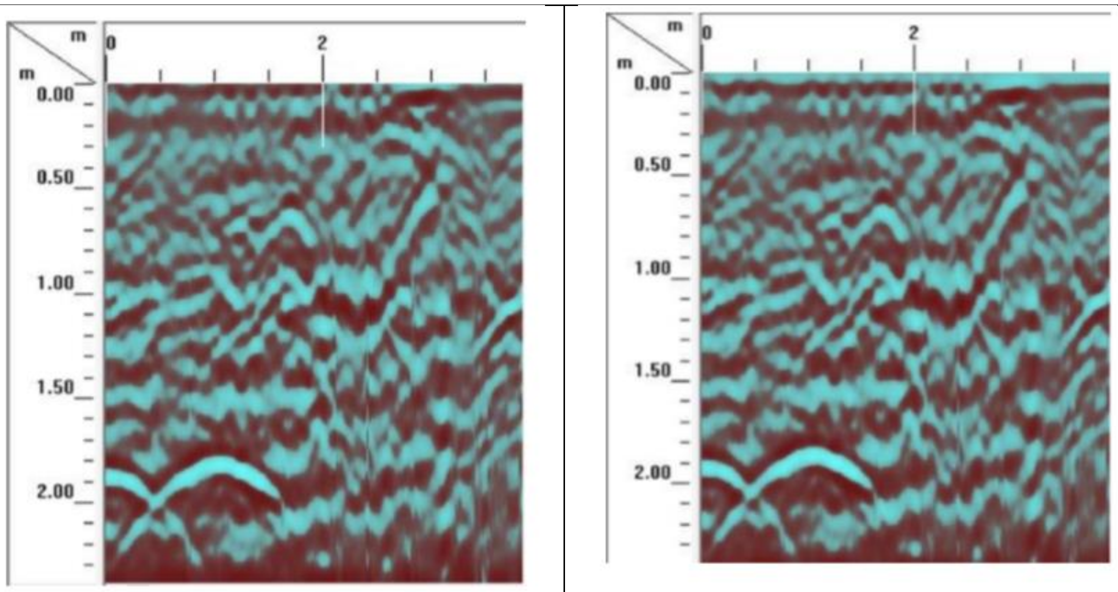
Standard Guideline for Underground Utility Mapping by Department of Survey and Mapping Malaysia (JUPEM) required accuracy of 10 cm (in vertical and horizontal direction) of the utilities mapped to be classified as Quality Level A. Results shows that GPR method manages to obtain the depth of embedded water pipe at both locations accurately up to Quality Level A mapping. Further, some other points nearby in Figure 2a) and b) are investigated using GPR. Table 3 shows the results, *D* of the embedded pipes. Based on Uniform Technical Guidelines for Water Reticulation and Plumbing by *National Water Service Commission* (SPAN), the underground water pipe must embedded 1 m or more from the ground surface. Results from Table 3 shows that the guideline is followed. Table 4 shows the coordinates of the points chosen at those 2 site locations.

Table 3
Depth of embedded water pipe at other points at site

	Type of surface	
	Soil	**Concrete**
No.	Depth (m)	Depth (m)
1	0.97	1.45
2	-	1.23
3	-	1.11
4	-	1.09

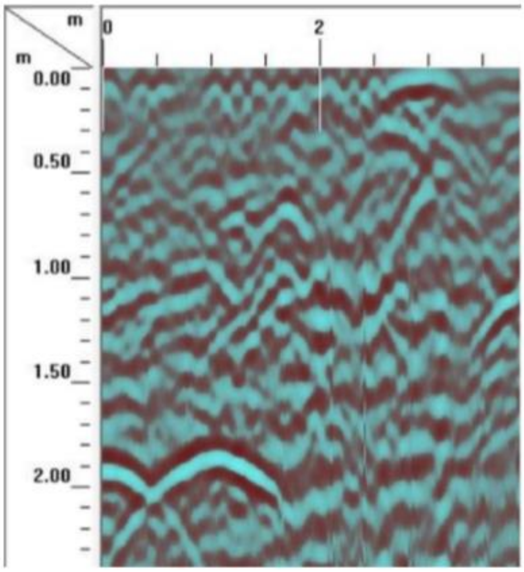
Table 4
Coordinate of the other points at site

Type of surface	**Soil**	**Concrete**
No.	Coordinate	Coordinate
1	N02.91957, E101.77121	N02.92370, E101.77328
2	-	N02.92368, E101.77331
3	-	N02.92367, E101.77331
4	-	N02.42366, E101.77331

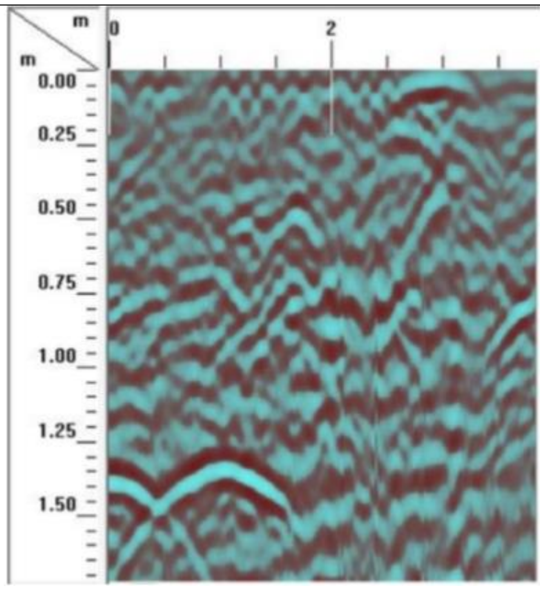


a) Profile 1 Original data collected from GPR

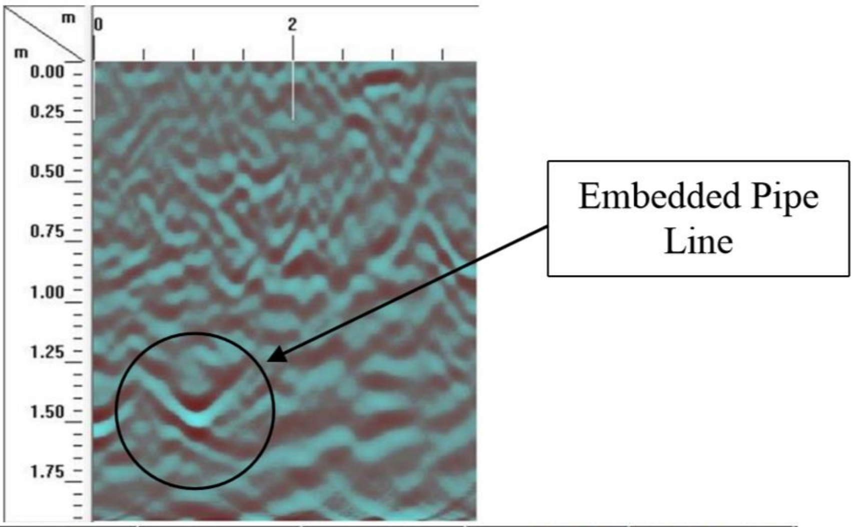
b) Profile 2 Data undergoes time zero correction process



c) Profile 3: Data undergoes background removal process



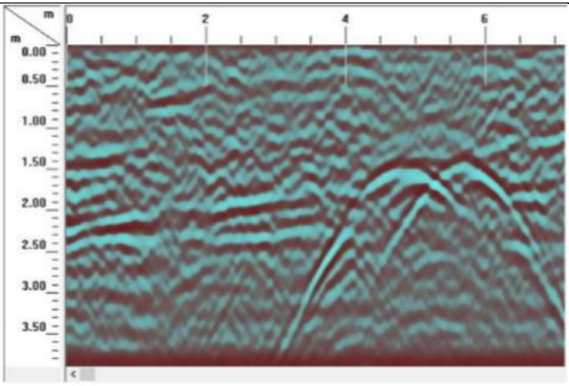
d) Profile 4: Data undergoes distance normalization process



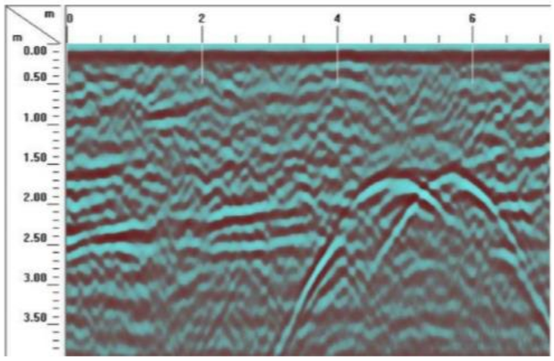
	Scan	Sample	Time	Depth(m)	Layer Vel.(m/ns)	Eff Vel.(m/ns)
1	0	416	36.56	3.113	0.000	0.085

e) Profile 5: Data undergoes kirchoff migration process.

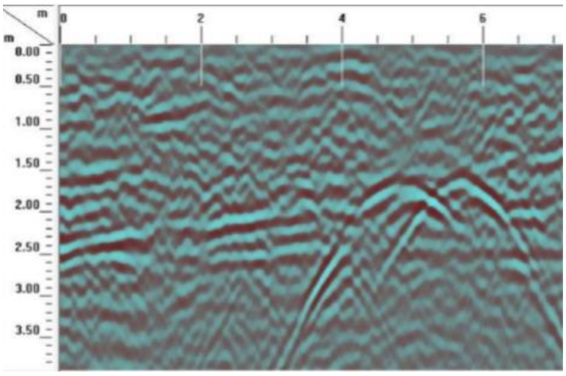
Fig. 5 a) – e)): Profile 1 to Profile 5 shows the processes from raw GPR data and the final analysis results using Radan 7. Site location: concrete medium. Coordinate: N02.92369, E101.77331.



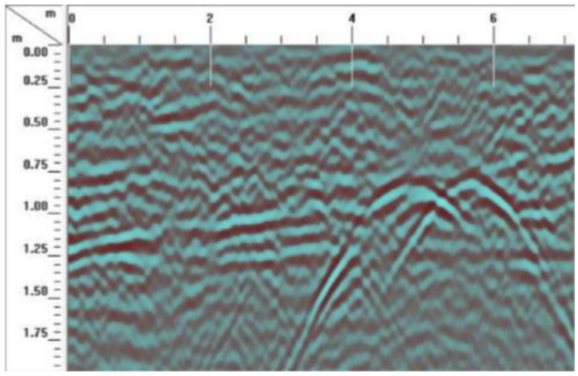
a) Profile 1 Original data collected from GPR



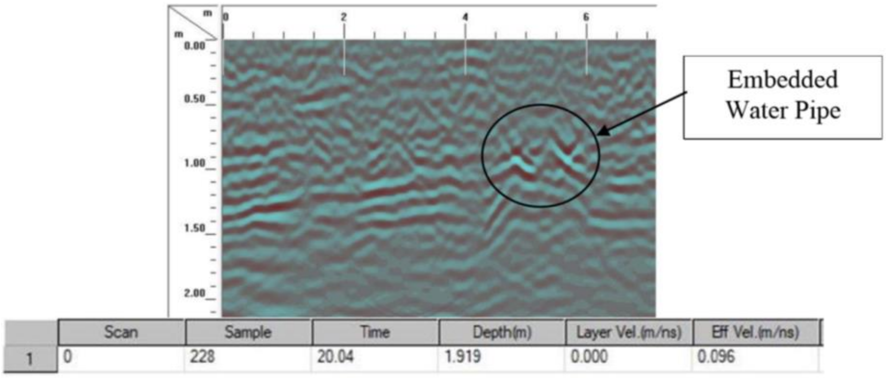
b) Profile 2 Data undergoes time zero correction process



c) Profile 3: Data undergoes background removal process



d) Profile 4: Data undergoes distance normalization process



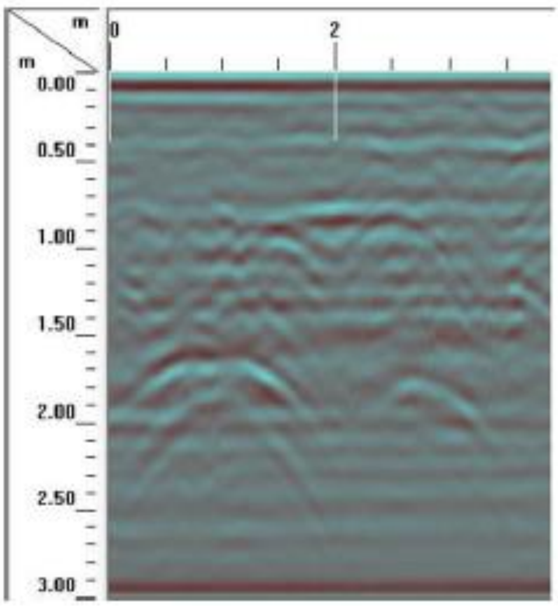
e) Profile 5: Data undergoes kirchoff migration process.

Fig. 6 a) – e): Profile 1 to Profile 5 shows the processes from raw GPR data and the final analysis results using Radan 7. Site location: soil medium. Coordinate: N02.91958, E101.77119.

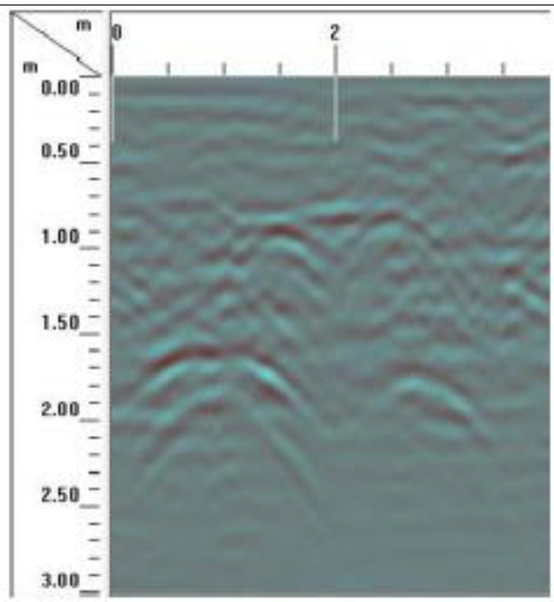
To complete the mapping of the pipeline to a building, location as Figure 2 c) is chosen where the inlet pipe is located so that we know that the pipe is buried nearby connected to the inlet. Figure 2 c) shows that the water pipe is buried under asphalt surface. Figure 7 a) – e) shows images of each process as described in Figure 4. The T and V_m of wave to reach pipe under concrete surface are 26.46 ns and 0.089 m/ns, respectively and from Eq. 1, the depth of embedded water pipe (D) at that location is 1.18 m. Table 5 shows other points nearby point at Figure 2 c) with their coordinates. With all the depths and locations of points determined, a mapping plan of pipes can be made by joining all the points. In this research only partial mapping plan of pipes from location at Figure 2a) and b) to a building Figure 2c) are determined. For complete mapping, the whole area can be investigated using GPR.

Table 5
Depth of embedded water pipe at other point at site

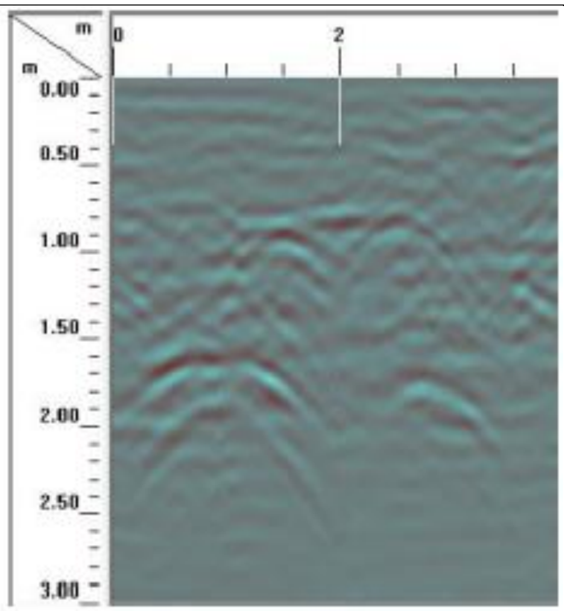
Type of surface	Asphalt	Asphalt
No.	Depth (m)	Coordinate
1	1.08	N02.92187, E101.77094
2	1.12	N02.92186, E101.77094



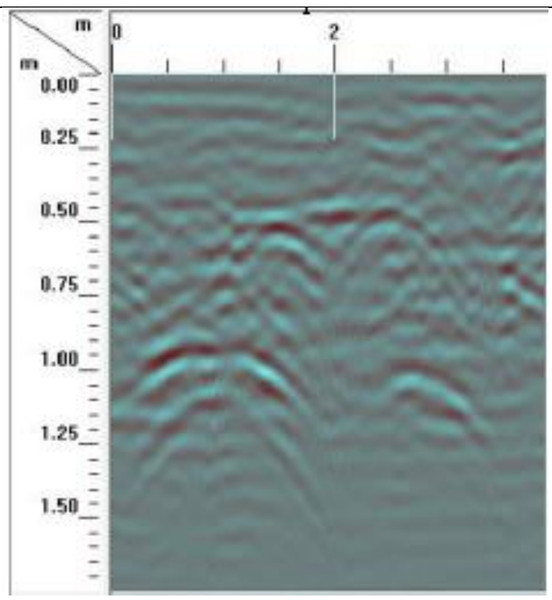
a) Profile 1 Original data collected from GPR



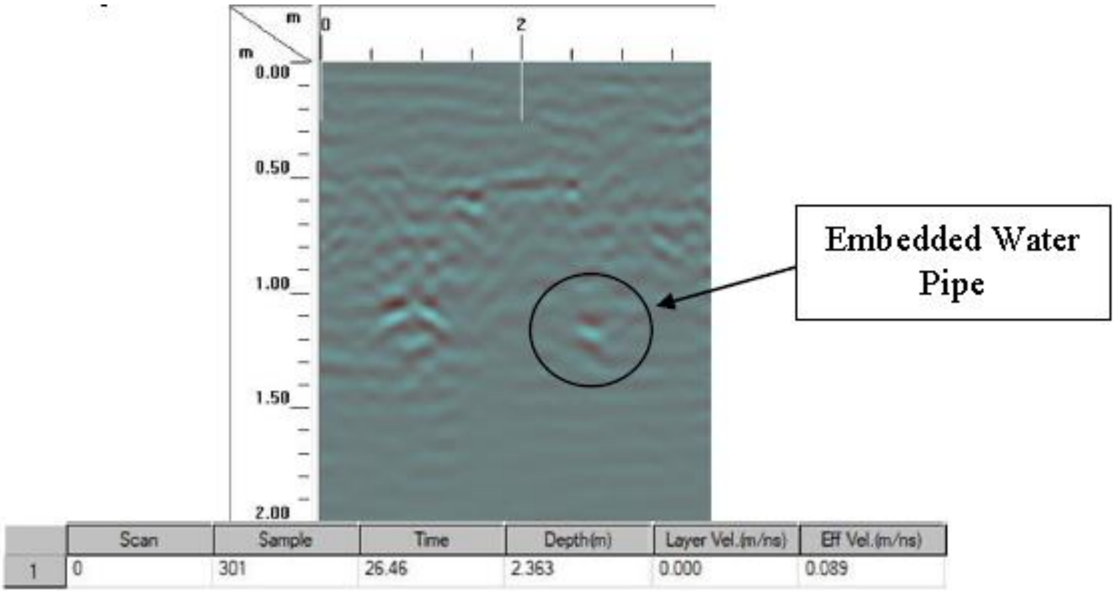
b) Profile 2 Data undergoes time zero correction process



c) Profile 3: Data undergoes background removal



d) Profile 4: Data undergoes distance normalization



e) Profile 5: Data undergoes Kirchhoff migration process

Fig. 7 a) – e): Profile 1 to Profile 5 shows the processes from raw GPR data and the final analysis results using Radan 7. Location: asphalt medium. Coordinate: N02.92189, E101.77094.

4. Conclusion

As a conclusion, GPR assisted with of Radan 7 software can measure the depths of buried pipes accurately with error of only 5% and 4% difference from actual depth in concrete and soils medium. Results shows that GPR method manages to obtain the depth of embedded water pipe at both locations accurately up to Quality Level A mapping based Standard Guideline for Underground Utility Mapping by Department of Survey and Mapping Malaysia (JUPEM) where the required accuracy of 10 cm (in vertical and horizontal direction) of the utilities mapped to be classified as Quality Level A which is the highest quality class for mapping underground utilities. Based on this verification, more underground buried pipes locations were determined, including under asphalts surfaces. With all the depths and locations of points determined, a mapping plan of pipes can be made by joining all the points. Finally, based on results of these site surveys, analysis of GPR electromagnetic waves to map underground pipe is proposed when Quality Level A is required and further mapping plan of underground pipe can be produced with help of GPR.

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