Accuracy Assessment on Underground Utility Equipment

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ABSTRACT

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This paper discusses about the accuracy and capability of underground utility equipment which is Ground Penetrating Radar (GPR) and Electromagnetic Locator (EML). The study area is located at JUPEM Underground Utility Detection Equipment Calibration Laboratory, Jalan Sultan Yahya Petra Kuala Lumpur. This study focused on accuracy, consistency and reliability of the both equipment due to the density of development especially in urban city areas poses new obstacles to new development which is the conflict of space. These issue raises when a new particular infrastructure needs to deploy in the same area with the crowded underground utilities. Here, the process of installation works for underground utilities need to be conducted carefully in order to avoid any utility accidents and casualties by determining the exact position and alignment of the existing underground utility. The common and the best option in the determination of any underground facilities are by underground utilities survey emphasized with buried objects which need to know the location installed and the depth deployed to ensure the safety of any development up coming. There are several methods with using different types of instruments include GPR, EML, Seismic Boom and Buried method. Thus, this paper is carried out for determining the accuracy of depth values obtained from GPR (Mala ProEx) and EML (RD8000) which are based on radar and electromagnetic concept respectively. Based on the result and analysis, it can be concluded that the accuracy achieved from GPR (Mala ProEx) is better compared with EML (RD8000). It has been proved by statistical data analysis in which the Root Mean Square Error (RMSE) values from GPR Mala ProEx for line A, line B and line C is smaller with millimeter level accuracy (3mm – 8mm) compared to EML RD8000 with centimeter level accuracy (18cm – 43cm). In term of reliability of dataset for the both types equipment for underground utility mapping, it shows that the range value of depth for all the types of utility is not significantly diverse. Fifty-six percent (56%) with centimeter level accuracy and Fourty-four percent (44%) with millimeter level accuracy.

***Keywords**: GPR, EML, Accuracy, Utility Mapping, Root Mean Square Error (RMSE)*

INTRODUCTION

Utility location is the process of identifying and labeling public utility mains that are underground. These mains may include lines for telecommunication, electricity distribution, natural gas, cable television, fiber optics, traffic lights, street lights, storm drains, water mains, and wastewater pipes. In some locations, major oil and gas pipelines, national defense communication lines, mass transit, rail and road tunnels also compete for space underground.

Maintaining the originality and the reliability of underground utility mapping and the database itself is an important task in undertaking planning for the development upgrading and maintenance of all infrastructures especially located below the ground surface. An underground utility mapping is referring to the position, location, and identification of any buried infrastructure and any buried object such as archeological things. There are a lot of utility detection and mapping focus like metallic and non-metallic, environmental assessment, damage prevention, geological investigation, turf assessment, archaeology, forensics, road inspection.

The modern world has an enormous and growing appetite for services many of which are delivered via pipes and cables, generally referred to as utilities, through the sub-surface of the ground. The business sector requires telephones, faxes and, increasingly, internet access. In spite of the growth of the mobile phone networks, telephone and internet services are also required. Water is brought in to both homes and businesses by pipeline and sewage pipes are used to transport grey water away.

The result of all of these activities is a growing conglomeration of pipes and cables buried beneath the feet. Obviously not all are at the same depth and equally obviously not all travel in the same direction. However, just as in cities there is a limit to the space available for houses, shops and other buildings above ground, the space below ground is also limited both for access and also for the amounts of utilities that contained stated by Erica Utsi (2012).

Ground Penetrating Radar (GPR) is a geophysical technique that is most effective with buried sites where artifacts and features of interest are located within 2–3 meters below the surface. A growing community of archaeologists has been incorporating GPR as a routine field procedure for landscape analysis. The maps and images act as primary data that enable to guide the placement of excavations, define sensitive areas containing cultural remains to avoid and place archaeological sites within a broader environmental context and study human interaction with, and adaptation to, ancient landscapes (Kvamme, 2003). GPR data is acquired by reflecting distinct pulses of radar energy from a surface antenna, reflecting them off buried objects, features or bedding contacts in the ground, and detected those reflections back at a receiving antenna. As radar pulses are being transmitted through various materials on their way to the buried target feature, their velocity will change, depending on the physical and chemical properties of the material through which they are traveling (Conyers, 2004).

In Malaysia, surveyor plays a major role for carry out the utility detection and mapping. The profession itself tells why surveyor is needed to take this responsibility of detecting and demarcating the utility line. According to Uren and Price (2006) surveying is a process of measuring angles, distances and height. Before surveyor has been given the responsibility to carry out utility mapping, contactors did the mapping and the accuracy and reliability of data in term of positioning was well questioned. By 1994, the Cabinet had announced that Department of Survey and Mapping Malaysia had been given the responsibility for utility mapping and monitoring projects. However, the department only managed to set up a Utility Mapping Section by 2005 due to the lack of resources and manpower (Berita Ukur, 2005). On 2010, it has already continued its development and all the information about the utility mapping in Malaysia has been kept in a database called as National Underground Utility Database.

To identifying all those buried things, a several methods come out with their own equipment and strength. Those are GPR, the Electromagnetic Locator (EML), the seismic wave, digging method and x-ray scanning. Detection will be obtained by applying any all those methods depend on project cost and demand.

In avoiding accidents and damages of underground utility during installation, guideline of utility maps that shown as built infrastructure is very important before applying any excavation on the ground surface level. As the result, today the utility mapping becomes a part of land survey professions in order to ensure the sustainable development.

LITERATURE REVIEW

Ground Penetrating Radar (GPR)

GPR also known as ground probing radar is a geophysical method which involves transmitting radio waves into the ground. The need to better understanding overburden conditions for activities such as geochemical sampling, geotechnical investigations, and placer exploration, as well as the factors controlling groundwater flow, has generated an increasing demand for techniques which can image the subsurface with higher resolution than previously possible.

GPR operating with transmitting radio waves into the ground. Then the radio waves are reflected by buried objects and return back up to the ground surface, which are detected by a receiver antenna. At the same time, the period of time taken for the radio wave to travel down into the ground and then back up to the receiver antenna is recorded by a computer. After that, the data's recorded will be calculated to determine the depth. However, the effectiveness of GPR in these activities is highly dependent on specific site area and the soil type. That was become a common concern of GPR service providers is whether the GPR equipment will be able to achieve the desired depth or not from penetration into the soils due to the major issue with GPR is the type of soil present. Water logged soils, such as silts and clays, will absorb radio waves and indirectly preventing them from traveling into the ground surface. Fig. shows the GPR type Mala ProEx.

Figure 1. Ground Penetrating Radar (GPR) Mala ProEx

In concept, the depth of GPR detection depends on the frequency of antenna used and the type of soil in the environment. Antenna selection depends on the purpose of underground utility detection. When the frequency is lower, then the wavelength is longer and then more detection process can be made.

Table 1 indicates the classification of frequencies with depth according to Department of Survey and Mapping Circular (PKPUP Bil. 1/2007).

Table 1. Antenna Frequency Specifications

Antenna	Frequency	Depth
High Frequency	> 1000 MHz	< 0.5 m
Medium Frequency (high)	400 – 600 MHz	0.5 m – 1.5 m
Medium Frequency (low)	200 – 400 MHz	1.5 m – 2.0 m
Low Frequency	< 200 MHz	2.0 m – 3.0 m

Source: (Department of Survey and Mapping, 2007)

Electromagnetic Locator (EML)

Figure 2. Electromagnetic Locator (EML) RD 8000

EML is also known as Pipe and Cable Locator (PCL) can be categorized as one of equipment that capable to identify any continuous metal, such as iron, steel and copper, water lines, gas lines, tracer wire by plastic pipe, telephone and television cables, copper and aluminum wire, conduit, and power lines whether energized or not, fiber optic lines, irrigation lines, power lines, streetlight wiring, water lines and sewer lines and many more.

PCL or EML have both functions which are working simultaneously between transmitter and receiver. The transmitter induces an electric current that circulates through an object creating a magnetic field and then detected by the receiver. In conclusion, the searching utility work with using EML is deemed required especially for the case of an existence of the electric current in the object sought. Figure 2 shows EML type RD 8000.

In concept, a transmitter emits electromagnetic waves, a magnetic field is generated. For any metal pipe or cable that is laid within the magnetic field, induced current is produced and flows through the underground metal pipe or cable according to the principle of electromagnetic. Then, a receiver picks up the magnetic field generated by the sub-surface metal pipe or cable. The location and depth of the sub-surface pipe or cable is located by the angle of the magnetic force concentrically generated by the metal pipe and the strength of the magnetic field. The magnetic field detected by EML around the line created by a current and forms a cylindrical shape known as a signal. To ensure with an accurate result, two (2) types of modes are proposed and normally being used as following:

a) Direct Connection

The output AC voltage from the signal transmitter is connected directly to the pipe or cable at an access point such as a valve, meter or end of the conductor, and the circuit is completed by a connection to a stake or the ground connection points. Figure 3 shows the concept of direct connection method.

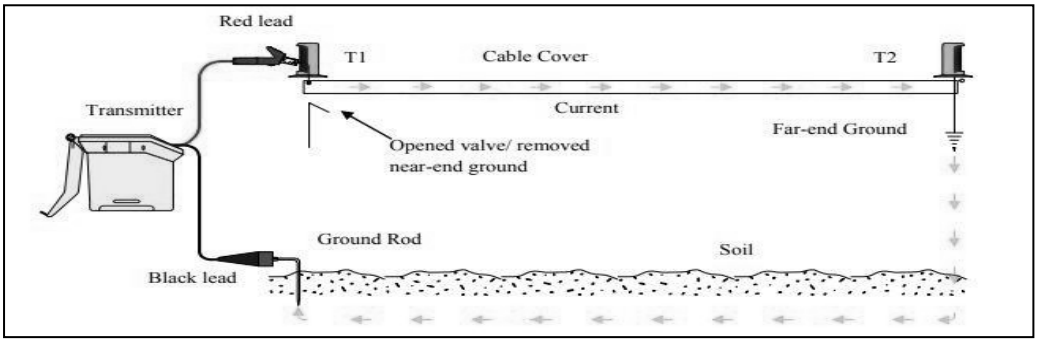

Figure 3. Concept of Direct Connection Method

b) Direct Induction (Clamping)

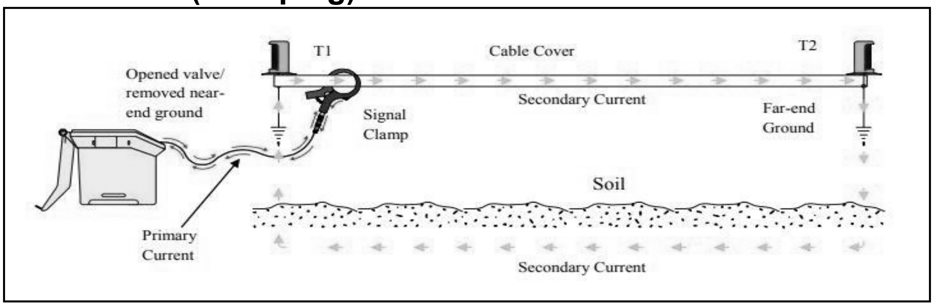

Figure 4. Concept of Direct Induction with Clamping Method

The direct induction method will give a similar result as a direct connection, without electrical contact to the line. The output from the signal transmitter is applied to a target line by clamping round it with a split toroid magnetic core, which carries a primary winding magnetizing the core with the AC signal. The line becomes the secondary of a transformer, and will carry a strong signal, provided that it is adequately grounded on each side. Figure 4 indicates the direct induction with clamping concept.

METHODOLOGY

The research methodology can be divided into three (3) main stages:

Stage I: Data collection by using GPR Mala ProEx and EML RD 8000 with determining the depths of the different types of underground utility objects.

Stage II: Data processing in which the data collection by GPR will be post-processed using REFLEX software and EML is manually recorded on the site.

Stage III: Data interpretation and analysis in terms of accuracy between two (2) types of instrument with using statistical analysis Root Mean Square Error (RMSE) in order to determine the consistency and capability of the both utility instrument between GPR and EML.

Figure 5 illustrates the flowchart of the research methodology in the general perspective of view.

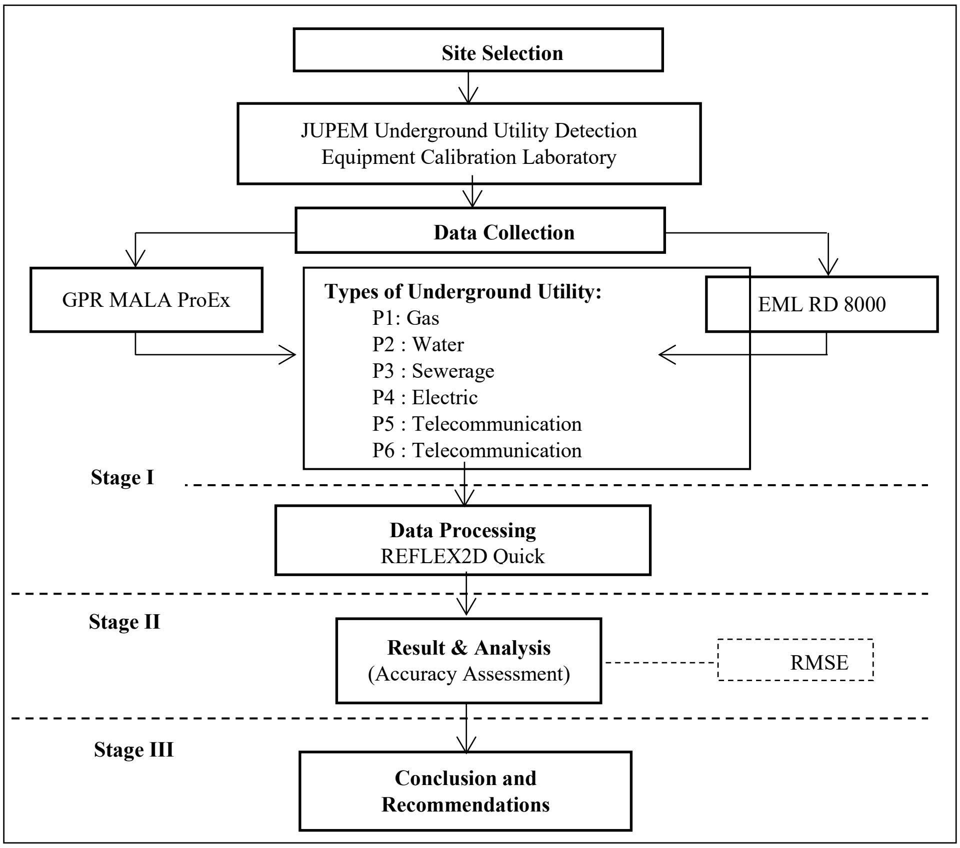

Figure 5. General Research Methodology flowchart

Research Study Area

The site selection for this study is located at Underground Utility Detection Equipment Calibration Laboratory (JUPEM), Jalan Sultan Yahya Petra Kuala Lumpur. The size of the platform is 10 meters x 10 meters of length and width, 3 meters for the high. It has special features in which accommodates six (6) different types of utility objects marked as P1, P2, P3, P4, P5 and P6 with different materials and allocated with different depths as shown in Table 2 and Fig. 6. The medium for the soil content of this test site consists of silica sand (0.6mm – 2mm) which based on the electromagnetic signal transmitted by the transmitter that can be strongly re-reflected to the receiver.

Table 2. The Specification of Special Features at Platform Calibration Laboratory

Underground Utility	Type	Material
P1	Gas	Metal
P2	Water	PVC
P3	Sewerage	Porcelain
P4	Electric	PVC
P5	Telecommunication	PVC
P6	Telecommunication	Fiber Optic

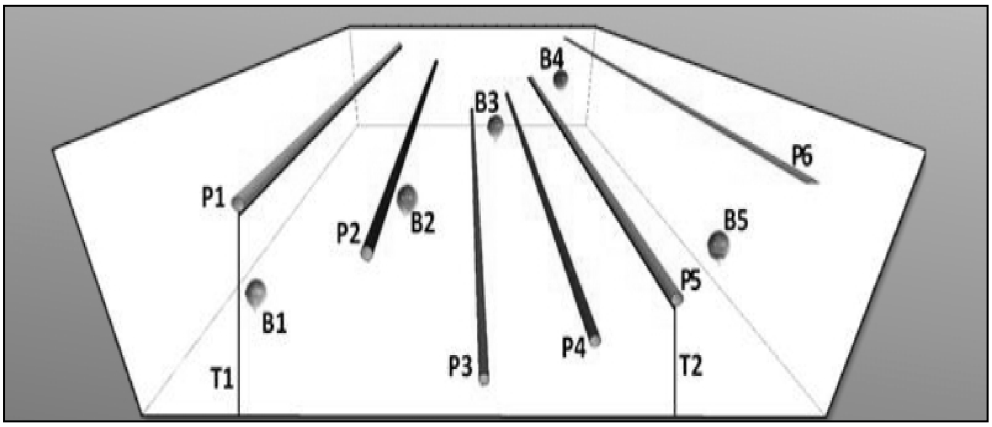

Figure 6. 3D Diagrams on the position of underground utility objects

The test base was developed to test the detection equipment based on electromagnetic technology and radar for the purpose of conforming to the specifications of underground utilities mapping accuracy. In short, it can be concluded that, this site study area is suitable approach especially for conducting research study in the assessment of accuracy towards utility equipment mapping.

Survey Work Detection

In an initial stage for fieldwork data detection, the EML RD8000 and GPR Mala ProEx equipment are installed and operated. In this stage, some of adjustments on both the equipment is configured in order to achieve the required standard.

The antenna used by GPR Mala ProEx is 500 MHz frequency which capable to detect the underground utility either it is metallic or non-metallic material. The 500 MHz frequency antenna is considered as medium high frequency which able to detect from 0.5m to 1.5m depth. It also produced a high resolution of hyperbolic radar gram image in the process of interpretation on the detection data by using REFLEX2D Quick software,

The EML RD8000 use 33 kHz frequency as a medium frequency. The direct connection method is being used for Metal (P1) and PVC (P5), while PVC (P2), Porcelain (P3), PVC (P4) and Fiber Optic (P6) are detected by induction method.

RESULT AND ANALYSIS

Based on the data collection perspective of view, all the data has been collected and recorded at Calibration Laboratory for Underground Utility Detection Equipment located in Department of Survey and Mapping Malaysia. Since there are three (3) lines namely as line A, B and C for every type of utility object as mentioned before (P1-P6), thus there are eighteen (18) observation data that has been collected. For data collected using GPR Mala ProEx, the radar grams (hyperbolic images) have been post-processed and analyzed with using REFLEX2D Quick software in order to determine the depth of utility objects.

Accuracy Assessment for GPR and EML

The statistical analysis with using Root Mean Square Error (RMSE) has been used and applied in order to identify the capability and accuracy data acquired between GPR Mala ProEx and EML RD8000. Since the fieldwork data collection is carried out at *JUPEM* Calibration Laboratory which provides the depth values as actual values for every utility object, thus the comparison values in term of depth between two (2) types of equipment with standard values are able to be determined. Tables below show the result and accuracy for the both equipment for line A, B and C.

Table 3. Result and Accuracy between GPR and EML for Line A

Utility Object	Standard Depth (m)	GPR Mala Pro Ex (m)	EML RD8000 (m)	Accuracy GPR Mala Pro Ex (±m)	Accuracy EML RD8000 (±m)
P1	0.448	0.434	0.533	0.014	0.085
P2	1.049	1.047	1.071	0.002	0.022
P3	2.537	2.536	2.495	0.001	0.042
P4	2.005	1.992	2.020	0.013	0.015
P5	1.251	1.250	1.237	0.001	0.014
P6	0.335	0.331	0.339	0.004	0.004

Table 4. Result and Accuracy between GPR and EML for Line B

Utility Object	Standard Depth (m)	GPR Mala Pro Ex (m)	EML RD8000 (m)	Accuracy GPR Mala Pro Ex (±m)	Accuracy EML RD8000 (±m)
P1	0.447	0.452	0.440	0.005	0.007
P2	1.049	0.999	1.061	0.005	0.012
P3	2.421	2.431	2.398	0.001	0.023
P4	1.932	1.922	1.921	0.001	0.011
P5	1.250	1.270	1.281	0.002	0.031
P6	0.322	0.317	0.308	0.005	0.014

Table 5. Result and Accuracy between GPR and EML for Line C

Utility Object	Standard Depth (m)	GPR Mala Pro Ex (m)	EML RD8000 (m)	Accuracy GPR Mala Pro Ex (±m)	Accuracy EML RD8000 (±m)
P1	0.435	0.431	0.409	0.004	0.026
P2	1.024	1.024	1.034	0.000	0.010
P3	2.423	2.419	2.429	0.004	0.006
P4	1.897	1.900	1.999	0.003	0.102
P5	1.253	1.253	1.261	0.000	0.008
P6	0.322	0.321	0.318	0.001	0.004

Based on Table 3, Table 4 and Table 5, the result from GPR Mala ProEx is more accurate compared with EML RD8000 in which, the accuracy obtained for six (6) types of utility object in millimetre level accuracy. For GPR equipment used, the penetrating concept is free from noise and other disturbance for metallic and non-metallic underground utility objects, while the data obtained from EML RD8000 with using induction method is less accurate and inconsistent in transmitting the electromagnetic waves due to the signal induced by the transmitter is keep fading and weaknesses of electromagnetic wave. However, the EML has lower sensitivity in detection of underground cables and pipes that made from PVC and fiber optic. In short as can be seen in the table 6, it can be concluded that the accuracy from GPR is better compared with EML due to a few of factors such as the method, concept of permittibility and reflection for underground detection.

Table 6 shows the Root Mean Square Error (RMSE) values from GPR Mala ProEx for line A, line B and line C is smaller with millimeter level accuracy compared with EML RD8000 with centimeter level accuracy.

Table 6. Accuracy values between GPR and EML by using RMSE Analysis for Lines A, B and C

Equipment	Line A RMSE (±m)	Line B RMSE (±m)	Line C RMSE (±m)
GPR Mala ProEx	0.008	0.004	0.003
EML RD8000	0.040	0.018	0.043

CONCLUSION

In the accuracy perspective of view, the site selection located at Underground Utility Detection Equipment Calibration Laboratory (JUPEM), Jalan Sultan Yahya Petra Kuala Lumpur becomes relevant as test base since the standard values of depth for different types of utility objects are provided. The study is carried out for determining the accuracy of depth values obtained from GPR (Mala ProEx) and EML (RD8000) which are based on radar and electromagnetic concept respectively. During the determination of accuracy with using GPR Mala ProEx and EML RD8000, it indicates that not all buried pipes, cables and ducts are able to be detected and mapped in the certain consideration of depth, location, material type, geology and proximity to other utilities due to limitation and difficulty in determining then actual depth. Based on the result and analysis, it can be concluded that the accuracy achieved from GPR (Mala ProEx) is better compared with EML (RD8000). It has been proved by statistical data analysis in which the Root Mean Square Error (RMSE) values from GPR Mala ProEx for line A, line B and line C is smaller with millimeter level accuracy (3mm – 8mm) compared to EML RD8000 with centimeter level accuracy (18cm – 43cm).

In term of reliability of dataset for the both types equipment for underground utility mapping, it shows that the range value of depth for all the types of utility between GPR (Mala ProEx) and EML (RD8000) is not significantly diverse. Fifty-six percent (56%) with centimeter level accuracy and Fourty-four percent (44%) with millimeter level accuracy. In other words, the both types of equipment are able to be used together for underground utility survey detection.

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