# Accuracy Assessment of GPR Data for Buried Objects with Different Pipes and Soil-Based Conditions

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**Abstract**

*In terms of accuracy and speed, Ground Penetrating Radar (GPR) is the best approach for detecting and identifying underground utilities. This technology can precisely find a wide range of underground utilities, including both metallic and non-metallic materials. It analyses the ground by emitting a signal from an antenna at various frequencies of electromagnetic (EM) pulses. However, undesirable echoes caused by heterogeneous materials, such as the wide range of soil properties and utilities, are always present in these reflected signals. The site's soil composition has a direct influence on the accuracy of the GPR signal image. Thus, this study is carried out to evaluate the accuracy of GPR data for buried objects with different types of pipes between PVC and iron pipe in different soil characteristics: fine sand, topsoil and silt soil. The objective is to interpret the resolution of radargram images on different soil types due to different soil based characteristics and to evaluate the accuracy of depth values between GPR and conventional survey data sets for different pipes and soils using the RMSE formula. GPR Electronic TriVue with high frequency (1GHz) was employed, and the resolution of the resulting radargram image was post-processed in ReflexW software to yield promising depth results. Based on this research, the radargram obtained shows different textures that provides different presentations of each soil on the radargram image. Accuracy assessment from RMSE depth difference for Iron pipe depth for the three different soil types are: topsoil is 0.025 m, silt soil is 0.032 m, and fine sand is 0.087 m. While for PVC pipe topsoil is 0.035 m, silt soil is 0.038 m, and fine sand is 0.093 m. These differences show that iron pipe is more accurate compared with PVC in terms of tendency and fine sand is suitable soil in detection compared with topsoil and silt soil. In conclusion, the type of pipe play role in the choice of utility and soil properties (texture, moisture, and electrical conductivity) that impact the most on the accuracy assessment of GPR Data.*

**Keywords:** Accuracy Assessment, GPR, Iron Pipe, PVC Pipe, Soil Based Content

## 1. Introduction

The utilization of Ground Penetration Radar are increasing with development civil and engineering work [1] and [2]. The term "underground utility detection" refers to identifying, separating and classifying underground utility object that located below the ground surface [3]. These utility objects include communication lines, telephones cables, fiber optics, water and wastewater conduits, electricity cables, oil and gas pipelines, mass transportation, road tunnels and rail [4]. Pipelines in subsurface utilities and other cylindrical objects would appear in black and white streaks with hyperbolic pattern on the GPR radargram [5]. In underground detection applications, undesirable echoes created by heterogeneous substances such as sand, clay, rock, gravel, and utilities are always present in these reflected signals. Most studies such as [6] and [7] have stated that the different soil compositions at the site will have a direct effect on the quality of radargram images and accuracy of GPR dataset.

Due to a good transmission to take place, magnetic and electrical waves must be unhindered as they interact with one another [8]. This paper is to assess the accuracy of GPR data for buried objects on different types of pipes (PVC & Iron pipe) with soil conditions (fine sand, topsoil and silt soil). Thus, this research will examine the accuracy of buried objects with different types of pipes and soil samples in one simulation testbed by RMSE. GPR is a non-destructive and non-invasive method based on high-frequency (usually from 1 MHz to 1000 MHz) electromagnetic wave propagation [9]. Consequently, the study's findings will reveal which varieties of soil and pipe material are easier and more accurate to identify using 1GHz GPR.

## 2. Methodology

The research methodology contains four (4) main stages. Figure 1 depicts the methodology flowchart in general perspective.

### *2.1 Project Planning*

Planning a project is a discipline that addresses the question of how to finish a project within a specified timeframe. One of the crucial steps is site reconnaissance. Field data collection is located at lot 1 Jalan Kristal 7/67a, 40450 Shah Alam, Selangor Darul Ehsan. This location was selected due to its wide space and the presence of excellent soil for dredging activities as shown in Figure 2 and Figure 3.

### *2.2 Testbed Dimension*

GPR measurements were taken on three (3) distinct soil types: fine sand, silt soil, and topsoil. Material distinctions, which were highlighted strongly in this research. The soil was excavated to a depth of roughly 0.5 metres, and all soil types were planted in the trenches. The trenches were to be roughly 1.5 metres in length and split into three pieces/divisions to represent the three kinds of soils, as seen in Figure 4. The final dimensions of the soil trenches were measured and split properly separated by plank wood measuring 10 mm x 0.5 m x 0.5 m, which assists in distinguishing the soil and prevent it from mixing, as illustrated in Figure 3.

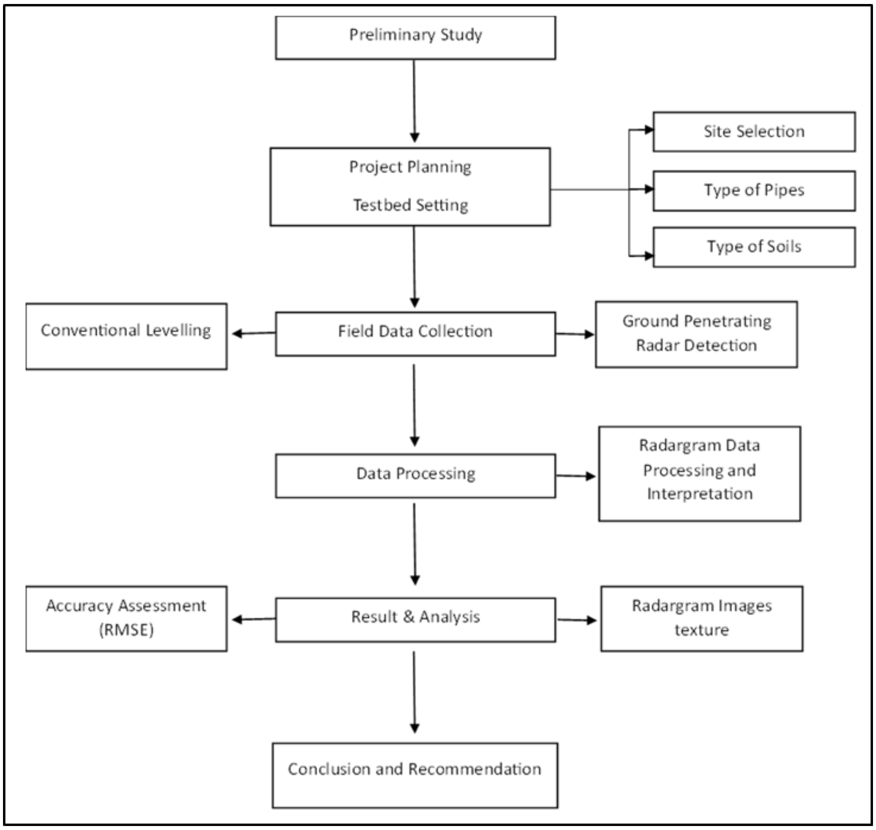


**Figure 1:** General research methodology flowchart


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**Figure 2:** Research area at Jalan Kristal, Shah Alam

**Figure 3:** Site condition

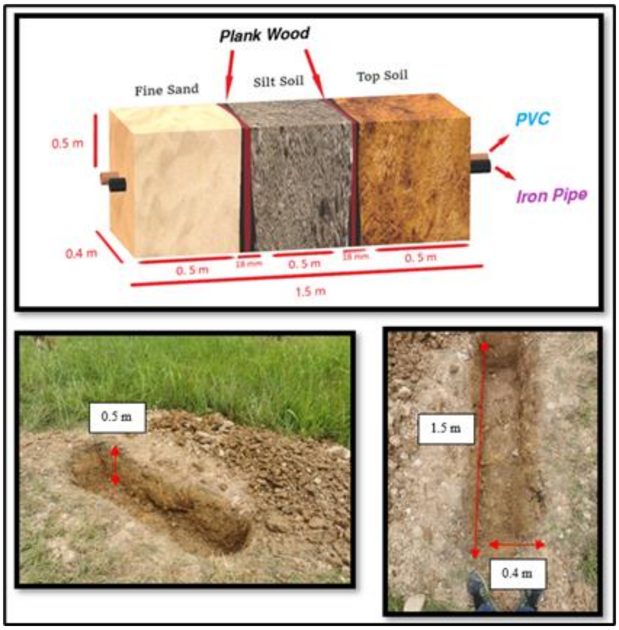


**Figure 4:** Testbed dimension and configuration


**Figure 5:** Specification of iron pipe and PVC pipe

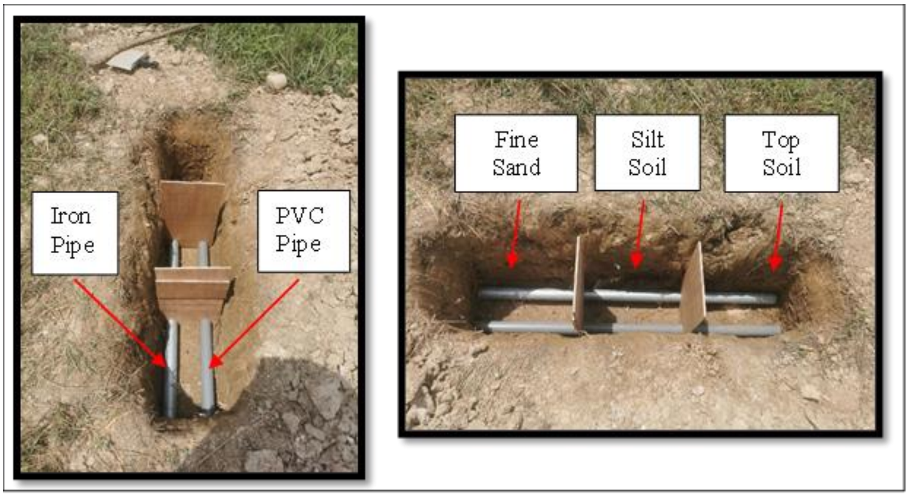


**Figure 6:** Site configuration of soil types

In this research, several types of pipes: PVC and iron pipe used as underground utilities. Figure 5 illustrates the length and diameter measurements for PVC and iron pipe, which are 1.5 metres (length) and 5 cm (diameter) respectively. The pipes were attached on plank wood as to make sure the pipe stationary when buried soil. These two types of pipes will be inserted into the hole at a depth of 0.5 m and different types of three soil will be buried at a depth specified to fit the surrounding soil's height as shown in Figure 6. The soils were chosen based on their characteristics. Fine sand is a form of soil that is dry and non-sticky, whereas topsoil is sticky and difficult to work with when wet, and it dries out quickly in the summer. The last type of soil is silt soil, which is comprised of incredibly microscopic particles that give the soil a smooth, slippery feel.

*2.3 Data Collection*

The field data collection was separated into two distinct approaches, namely GPR detection and levelling survey as conventional method. The equipment used for this phrase; UTSI Electronic TriVue for GPR detection (a) and Auto Level for levelling (b) as shown in Figure 7. Levelling is a conventional approach applied before and after the object is buried to achieve depth values as shown in Figure 8. The depth values for six (6) points are used as the most probable value in which to assess the accuracy of GPR data in term of depth. GPR detection was taken on three (3) distinct soil types: fine sand, topsoil, and silt soil as shown in Figure 9. The observation used the Two-Way Travel Time (TWT) technique, in which the signal was transmitted in subsurface and received signal was reflected into the receiving antenna.


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**Figure 7:** Equipment used in field data collection; (a) GPR equipment and (b) Auto Level

(a) (b)

**Figure 8:** Levelling technique; (a) Before and (b) After buried object

**Figure 9:** GPR scanning and detecting process

The optimal frequency with high frequency category used for collecting data with 1 GHz. The GPR detection are performed eight (8) times in order to obtain a good and consistent of underground utility dataset in term of depth values.

*2.4 Data Processing*

In this stage, the image obtained from GPR detection must be post-processed to acquire radargram image with a better resolution using ReflexW software. The radargram images were cleaned up by filtering them in the ReflexW software to get rid of noise including ringing noise and time delay, and to improve the brightness and contrast. In data interpretation phase, the depth values for eight (8) scan number of dataset are produced and determined. The filtering procedure for a radargram images with ReflexW software is shown in Figure 10.

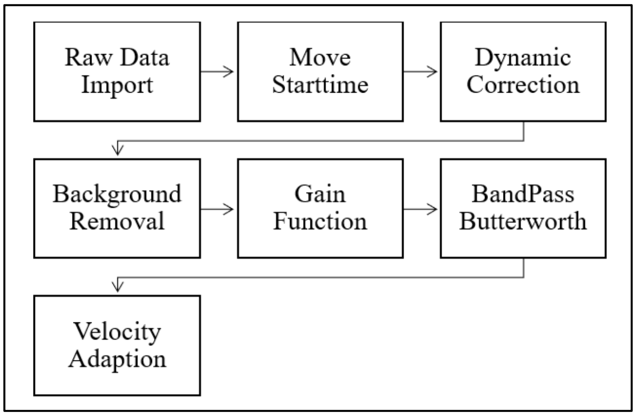



**Figure 10:** Flowchart of post-processing using Reflexw Software

Furthermore, Root Mean Square Error (RMSE) statistical analysis has been employed and applied to determine the accuracy and reliability of GPR data. The RMSE of the depth from GPR is derived by comparing the depth value obtained from the GPR image with the depth measured from the levelling value based on conventional method. The accuracy of detection is calculated by the RMSE calculation for each utility observed. The RMSE equation is shown in equation as below:

$$RMSE = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{n}\left|Z_0 - Z\right|^2\right)}$$

Equation 1

For levelling method, which using Rise & Fall method to transfer heights from TBM to the pipe before and after buried with soil in order to determine the depth values for underground pipes with different soil conditions.

## 3. Results and Discussion

### *3.1 Actual Depth Values from Conventional Method*

In order to determine the depth of underground pipes from ground surface level, the depth values for pipe underneath which is before buried objects and height values of ground level which is after buried objects is required. Table 1 shows the depth values (m) for six (6) points which based on different types of two (2) pipes between PVC and Iron Pipe located in three (3) types of soil include topsoil, silt soil and fine soil.

### *3.2 Radargram Images Interpretation*

The comparison of data visualization in term of texture on the radargram images between three (3) different types of soil conditions is quite significant. Each type of soil described with various characteristics that distinguishes it from others as described in Table 2.

### *3.3 Accuracy of GPR Depth Dataset*

In assessing the accuracy of GPR data, all the depth values with six (6) points obtained from GPR data are evaluated with compared to the depth values from levelling method as actual values. Thus, the accuracy for each pipe between PVC and Iron pipe located in different types of soil conditions is shown in Table 3: Topsoil, Table 4: Silt Soil and Table 5: Find Sand.

## 4. Discussion

Ground Penetrating Radar (GPR) is a high resolution electromagnetic technique that is used to investigations in the shallow subsurface of the earth [10]. The accuracy of GPR data in terms of depth is defined by using RMSE statistical model. There are six (6) results of RMSE since there are two (2) different types of pipes (Iron pipe and PVC Pipe) located in three (3) different types of soil. Table 6 and Figure 10 show the result of RMSE depth data on three (3) different types of soil. Based on the graph in Figure 11, it shows the most significant difference between two (2) types of pipes that located on three (3) types of different soil. Based on different types of pipes, it can be concluded that iron pipe is more accurate in term of tendency of detection by GPR compared with PVC pipe.

RMSE values for iron pipe located on topsoil, silt soil and fine sand are 0.025, 0.032 and 0.087 respectively. While RMSE values for PVC pipe located on topsoil, silt soil and fine sand are 0.035, 0.038 and 0.093 respectively. In short, it also can be concluded that topsoil and silt soil are less disrupt to GPR signal compared to fine sand. The soil properties structures (texture, moisture, dielectric permittivity, conductivity, and magnetic permeability) have ability to influence the accuracy on GPR dataset. These soil properties are critical in measuring the strength of the signal returning to the GPR unit [11]. Soil with high water content has high conductivity than dry soil. This shows that moist or wet soil has high conductivity than dry soil [12].

**Table 1:** Depth values for Iron Pipe and PVC Pipe with different types of soil based condition

| Type of Soil | Type of Pipe | Ground Level (m) | Pipe Underneath (m) | Depth (m) |
|---|---|---|---|---|
| **Top Soil** | PVC | 9.357 | 9.843 | **0.486** |
| | Iron Pipe | 9.365 | 9.850 | **0.485** |
| **Silt Soil** | PVC | 9.364 | 9.855 | **0.491** |
| | Iron Pipe | 9.358 | 9.852 | **0.494** |
| **Fine Sand** | PVC | 9.325 | 9.871 | **0.546** |
| | Iron Pipe | 9.326 | 9.858 | **0.532** |

**Table 2:** Depth values for Iron Pipe and PVC Pipe with different types of soil based condition

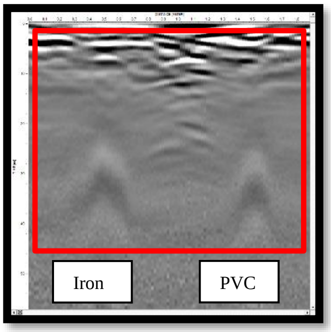
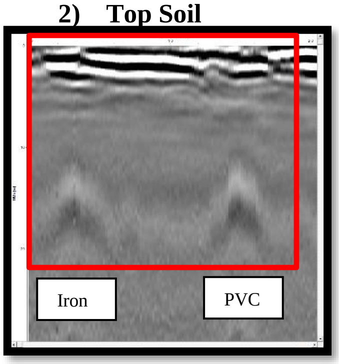
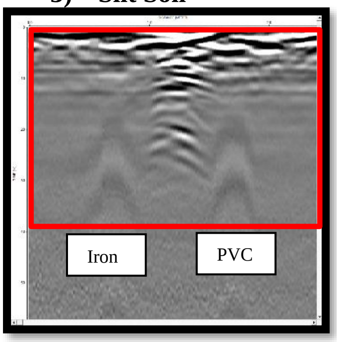
| Radargram Images | Radargram | Texture |
|---|---|---|
| **1) Fine Sand**<br><br> | The appearance of the parabolic Iron & PVC pipe is clear and easy to interpret after processing | The texture for the fine sand with small particle surface and has a bit void |
| **2) Top Soil**<br><br> | The appearance parabolic of the pipe is clear for Iron Pipe and PVC pipe and easy to interpret after processing | The texture for the topsoil is finer than the surrounding texture compared with silt soil and fine sand |
| **3) Silt Soil**<br><br> | The Iron and PVC Pipe parabolic more upward compared to others and there is void in the middle of image | The texture for the Silt Soil has the highest rough surface compared with fine sand and topsoil |

**Table 3:** Depth accuracy of iron pipe and PVC for top soil

| ***No. of GPR Scan*** | ***Topsoil*** | | | | | |
|---|---|---|---|---|---|---|
| | **Iron Pipe (m)** | **Levelling (m)** | **Accuracy (m)** | **PVC Pipe (m)** | **Levelling (m)** | **Accuracy (m)** |
| ***1*** | 0.493 | 0.485 | 0.008 | 0.5 | 0.486 | 0.014 |
| ***2*** | 0.493 | | 0.008 | 0.497 | | 0.011 |
| ***3*** | 0.494 | | 0.009 | 0.498 | | 0.012 |
| ***4*** | 0.494 | | 0.009 | 0.5 | | 0.014 |
| ***5*** | 0.493 | | 0.008 | 0.499 | | 0.013 |
| ***6*** | 0.495 | | 0.01 | 0.498 | | 0.012 |
| ***7*** | 0.494 | | 0.009 | 0.497 | | 0.011 |
| ***8*** | 0.495 | | 0.01 | 0.498 | | 0.012 |
| ***Average*** | 0.494 | | | 0.498 | | |
| ***Total Square Error*** | | | 0.000635 | | | 0.001235 |
| ***RMSE*** | | | **0.025** | | | **0.035** |

**Table 4:** Depth accuracy of iron pipe and PVC for silt soil

| ***No. of Scan GPR*** | ***Silt Soil*** | | | | | |
|---|---|---|---|---|---|---|
| | **Iron Pipe (m)** | **Levelling (m)** | **Accuracy (m)** | **PVC Pipe (m)** | **Levelling (m)** | **Accuracy (m)** |
| ***1*** | 0.505 | 0.494 | 0.011 | 0.504 | 0.491 | 0.013 |
| ***2*** | 0.505 | | 0.011 | 0.505 | | 0.014 |
| ***3*** | 0.506 | | 0.012 | 0.504 | | 0.013 |
| ***4*** | 0.505 | | 0.011 | 0.505 | | 0.014 |
| ***5*** | 0.506 | | 0.012 | 0.504 | | 0.013 |
| ***6*** | 0.506 | | 0.012 | 0.505 | | 0.014 |
| ***7*** | 0.505 | | 0.011 | 0.505 | | 0.014 |
| ***8*** | 0.505 | | 0.011 | 0.504 | | 0.013 |
| ***Average*** | 0.505 | | | 0.505 | | |
| ***Total Square Error*** | | | 0.001037 | | | 0.00146 |
| ***RMSE*** | | | **0.032** | | | **0.038** |

**Table 5:** Depth Accuracy of Iron pipe and PVC for Fine Sand

| ***No. of Scan GPR*** | ***Fine Sand*** | | | | | |
|---|---|---|---|---|---|---|
| | **Iron Pipe (m)** | **Levelling (m)** | **Accuracy (m)** | **PVC Pipe (m)** | **Levelling (m)** | **Accuracy (m)** |
| ***1*** | 0.5 | 0.532 | -0.032 | 0.512 | 0.546 | -0.034 |
| ***2*** | 0.5 | | -0.032 | 0.514 | | -0.032 |
| ***3*** | 0.501 | | -0.031 | 0.514 | | -0.032 |
| ***4*** | 0.502 | | -0.03 | 0.513 | | -0.033 |
| ***5*** | 0.501 | | -0.031 | 0.513 | | -0.033 |
| ***6*** | 0.502 | | -0.03 | 0.512 | | -0.034 |
| ***7*** | 0.502 | | -0.03 | 0.512 | | -0.034 |
| ***8*** | 0.502 | | -0.03 | 0.514 | | -0.032 |
| ***Average*** | 0.501 | | | 0.513 | | |
| ***Total Square Error*** | | | 0.00757 | | | 0.008718 |
| ***RMSE*** | | | **0.087** | | | **0.093** |


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**Table 6:** RMSE depth data between different types of pipes and soil

| Type of Soil | Type of Pipe | RMSE Depth (m) |
|---|---|---|
| **Top Soil** | Iron Pipe | **0.025** |
| | PVC Pipe | **0.035** |
| **Silt Soil** | Iron Pipe | **0.032** |
| | PVC Pipe | **0.038** |
| **Fine Sand** | Iron Pipe | **0.087** |
| | PVC Pipe | **0.093** |

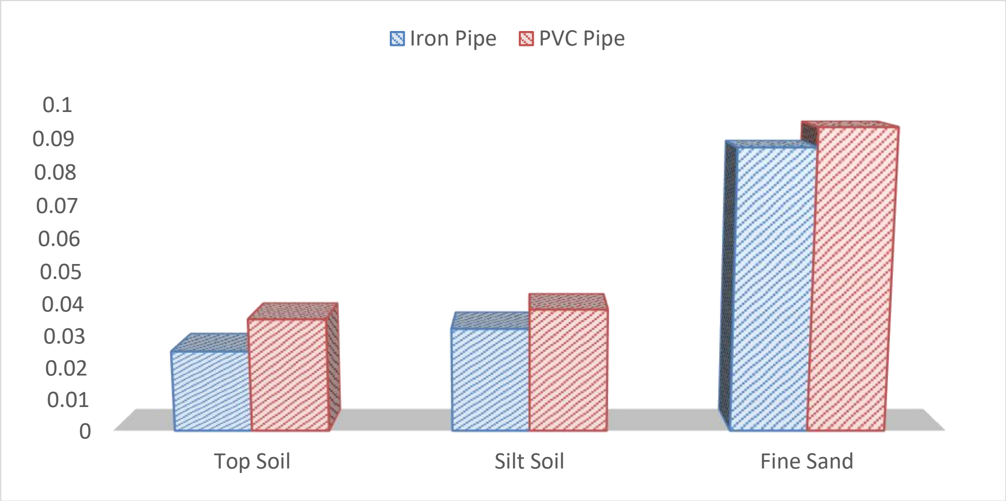


**Figure 11:** Graph of RMSE depth data between different type of pipes and Soil based conditions

## 5. Conclusion

In complex construction and large infrastructure areas, the lack of information about the subsoil may lead to damage of buried infrastructure during excavation and interruption of crucial services, inducing high repair costs and delaying construction [13]. Based on the research outcomes, first, the radargram obtained shows different texture that giving different presentation for each soil on the radargram images. It can be concluded that each type of soil has its own structure that may impacts on how the radargram appears. Second, the different types of underground utilities (Iron Pipe and PVC Pipe) also may influence in term of the tendency of detection by GPR. Iron Pipe is more accurate compared to PVC in term of accuracy with RMSE statistical model. Furthermore, based on the soil properties structures (texture, moisture, and electrical conductivity), fine sand the is least suitable for soil in detection compared to topsoil and silt soil.

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