Accuracy assessment of NOGGIN Plus and MALÅ RAMAC X3M single channel ground penetrating RADAR (GPR) for underground utility mapping

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Abstract. Ground Penetrating Radar (GPR) becomes a popular device in investigation of the underground utilities in recent years. GPR analyses the type and position of utility objects. However, the performance accuracy of GPR models is an important issue that should be considered. This study conducts the accuracy analysis between two models of single channel GPR; NOGGIN PLUS and MALÅ RAMAC X3M, by focusing on the basic principles of single channel GPR, accuracy analysis and calibration methods implemented on GPR. The survey work has been performed to identify the most accurate instrument to detect underground utility objects. In addition, data analysis was carried out to compare between two models of single channel GPR. This study provides proper guidelines and assists surveyors to select the suitable instruments regarding on applications especially on utility mapping in terms of accuracy.

1 Introduction

There are several approaches have been proposed for land utility surveying and other manmade subsurface structures [1]. In terms of utility survey, utilities are some kind of buried objects under the ground that can be measured, identified and then determined by using the instruments [2-4]. Basically, the product of utility survey is utility maps of for examples; gas pipes, metal and plastic pipes, sewage, electricity cables, telephone cable and pipes etc. There are two basic approaches of utility mapping; active systems that are connected to the utilities, and passive systems that work without connection [1, 5].

Regarding Malaysian perspectives, utility surveying was not specially supported by any authorizing organizations [6]. Recently, utility survey is sheltered under the Department of Survey and Mapping Malaysia (DSMM) which located in Utility Section. Nowadays with the rising of GIS and remote sensing technology, there are various kinds of instruments or tools exist in market place. The utilities sector is complex and changing rapidly in terms of instrumental developments [6]. Different instruments have their own functions and specific usage. More recent developments, that been used for acquiring utilities data are Pipe and Cable Locator (PCL) and Ground Penetrating Radar (GPR) [7-9]. The usage of GPR is applied in many applications including environmental application, engineering application, earth science application and more other applications [10-13]. In engineering application,
GPR is not only focusing on surveying, it has been used in many other applications such as constructions, unbound pavement structures, wall condition, etc [14]. In utility mapping application, GPR can provide three dimensional (3D) image of surface which depends on the specification of the model [15]. Malaysia has experienced the growth of utility survey with increasing number of utilities survey instruments.

As a related study conducted in Malaysia Najua S. [6] performed a comparison analysis between PCL and GPR; build up utility database and three dimensional modelling of utility mapping. Jol H. [16] expanded the usage of GPR as the utility instrument based on the level of accuracy between two different models of GPR. The rising of technology of utility instruments makes a difficult situation for surveyors and other users in ascertaining suitable instruments, used to detect underground objects with high accuracy [17]. In response of this issue, the current comprehensive study have been conducted in three objectives; to get information on basic principle of single channel GPR; to analyze the accuracy between two different models of single channel GPR; and identifying GPR calibration method. This study will significantly improve and ease the approaches of utility data collection.

2 Study area and material

The location of study area was at GPR, Pipe and Cable Locator, Test Base, Jabatn Ukur dan Pemetaan Malaysia (JUPEM) Kuala Lumpur. This site was selected to fulfil the objectives of the study, whereby existing underground utilities such as water pipes, electric cables, and telecommunication cables were buried underground.

The instruments used were single channel NOGGIN PLUS and MALÅ RAMAC X3M Ground Penetrating Radar (GPR) provided by Utility Section, DSMM. Data processing and interpretation was processed using software provided by Utility Section, DSMM.

3 Methodology

3.1 Survey design

Survey design is the first requirement for most of the study implementation. It can be assumed as planning process in initial steps before conducting survey work, especially, where measurement lines were designed. In this study, survey design was divided in two categories; first, measurement lines were designed in paper; and second, design was input in the instruments itself before the actual survey work begin. Moreover, survey design were determine based on the area of survey. The survey line was designed based on Y line only, forward, with 1 meter station interval. The area was designed with (6×6) metres as shown in Figure 1.

![Figure 1. Survey design.](image-url)
3.2 Survey planning
Survey planning is the method on how the survey will be started and ended. Firstly, before the actual survey starts, it is necessary to do reconnaissance work. Reconnaissance work is needed to explore the area of study and also to figure out various kinds of underground utilities involve at the survey site [18]. This method requires determining any obstacles that maybe encounter during survey work so that it can be ran smoothly without long time consumption. The second method was control survey with aim of establishing a control point at the survey area and to get the position of the survey site. Control survey is important part of this work to identify the location coordinates of the underground utilities. This control survey was performed using GPS instrument. Furthermore, the last method is detection survey or underground utility survey by using GPR.

3.3 Field work
This study requires two field work surveys as control survey and underground utility survey. A control survey requires to determine the position of the survey area. This is important in order to get accurate data positioning during data collection. GPS instrument, TOPCON GR-3 receiver with FC-200 controller was used for this process. Real Time Kinematic (RTK) GPS technique was used to obtain the coordinate of the unknown points. Before the survey was carried out, the receiver was set up at unknown point as shown in Figure 2. Then receiver was turn on to connect with Geodesy Section of DSM to get correction data from Malaysia Active GPS System (MASS) station with radio link communication.

3.4 Underground utility survey
Underground utility survey was started after the completion of control survey. The purpose of using GPR is to detect the destructive and non-destructive underground utilities. Two different models of single channel GPR were used; NOGGIN PLUS and MALÅ RAMAC X3M, to evaluate the level of accuracy and image quality.

3.5 Data processing
Noggin data was processed using two software; EKKO View and EKKO Mapper. In addition, Ground Vision and Object Mapper software were used for MALÅ RAMAC X3M data view. The function of the software is for data entry, data analyse and summarization of the data measurements in automated format. Moreover, data processing involves recording data measurements, analysing,
sorting summarising, data storing etc. Typically, data processing manipulates the raw data into information in order to produce outputs.

The flowchart of the methodology is shown in Figure 3.

![Flow chart of methodology.](image)

**Figure 3.** Flow chart of methodology.

4 Results and discussion

Image interpretation was done on GPR images for the purposes of identifying utility objects and their properties. The principle of image interpretation is according to the elements of the image such as colour, shadow, resolution, texture, pattern and depth. Image interpretation was done by comparing images collected by two GPR models (NOGGIN PLUS and MALÅ RAMAC X3M). NOGGIN images had clearer appearance compared to MALÅ images due to better image resolution. Based on images analysis in Adobe Photoshop Elements 8 software, NOGGIN model produces colour image while MALÅ default images were gray scale. This investigation was done to determine the depth and images pattern from detection survey. By using antenna of 250 MHz for both instruments, the survey was done in seven lines, but only the profile of line 4 and line 5 were analysed. The time interval and depth analysis were applied on these two profile lines. Same velocity (100 m/µsec) were applied on both instruments to determine the depth of water pipe and electric cable.

Figure 4 shows the interpretation image of line 4 which was taken by NOGGIN model. In this image, the blue hyperbola shape indicates water pipe underground utility while the red hyperbola shape indicates electric cable. The curvature of the dashed white line, represent hyperbola shape,
indicates the interference of objects. Depth and time intervals are shown in Table 1. From survey, the detection of depth 1.3 m was taken in duration of 24 ns for water pipe while for electric cable the depth 1.35 m was noted in 25 ns.

The survey was repeated for line 5 in same place. Line 5 is the connection of line 4 to observe the relation of the utility objects. From NOGGIN image, Figure 5 shows the different colour lines which blue lines illustrate water pipe, red lines illustrate electric cable and white lines indicate interference of objects in survey line 5. Y-axis shows the time interval and depth while the X-axis shows the distances. Table 2 explains Figure 5 in terms of depth and time interval. A depth of 1.3 m for water pipe was taken within 23 ns time interval while depth of 1.35 m of electric cable was noted in 25 ns time intervals.

Figure 4. NOGGIN line 4.

Table 1. Depth vs time NOGGIN line 4.

| LINE 4 | Type          | Time (ns) | Depth (m) |
|--------|---------------|-----------|-----------|
|        | Water pipe    | 24        | 1.3       |
|        | Electric cable| 25        | 1.35      |
Figure 5. NOGGIN line 5.

| LINE 4 | Type            | Time (ns) | Depth (m) |
|--------|-----------------|-----------|-----------|
|        | Water pipe      | 23        | 1.3       |
|        | Electric cable  | 25        | 1.35      |

Figure 6 shows the image of line 4 which is taken by MALÅ. This image shows water pipe and electric cable by different colour of lines. Table 3 shows depth and time interval for this stage. For water pipe, a depth 1.4 m taken in 26 ns and for electric cable a depth 1.5 m was illustrious in 27 ns.

Figure 7 shows the MALÅ image with the blue and red lines for water pipe and electric cable respectively. Instead of those lines, it has white line which indicates the noise of objects. Based on the scale reading from Figure 7, Table 4 explains a depth of 1.3 m was detected in 26 ns for water pipe while depth 1.4 m was detected in 27 ns time interval for electric cable.
The results show that, there are a few differences in terms of depth measured from both instruments with the original depth from the previous measurement. The original depth of water pipe was 1.5 m while electric cable had depth of 1.4 m. The average value of utilities measured between line 4 and 5 have been counted, water pipe had depth of 1.3 m with NOGGIN model and 1.35 m for MALÅ model. Electric cable depth average was 1.35 m and 1.45 m for NOGGIN and MALÅ respectively. From the value compared in this analysis, GPR indicates accuracy up to cm-level.

Table 5 shows the comparison value of depth measured with the original value while Figure 8 represents the comparison value of Table 5 in bar graph.
Figure 8. Data comparison.

Table 6 shows the difference between NOGGIN and MALÅ which counted from the average value of depth. Difference depth of 0.2 m for water pipe and depth of 0.05 m for electric cable are the difference between NOGGIN and original depth. On the other hand, different values of depth 0.15 m for water pipe and depth of 0.05 m for electric cables are from MALÅ model. It shows that, GPR instrument can provide cm-level accuracy in assessment between measurement values and original values.

Table 6. Value differences from the average counted values.

|        | Water pipe | Electric cable |
|--------|------------|----------------|
| Depth (m) |            |                |
| NOGGIN  | 0.2        | 0.05           |
| MALÅ    | 0.15       | 0.05           |

5 Conclusion and recommendations

GPR has potential capabilities in various applications especially in utility mapping field. This technology is widely applied in the last decades to discover the subsurface phenomenon. As it is well known, GPR can give better accuracy compared to other instruments such as Pipe Cable Locator (PCL) in terms of producing high resolution image. This study can assist the surveyors and other users to make the selection between two models of single channel GPR either NOGGIN PLUS or MALÅ RAMAC X3M based on the output results. In order to determine which models can give better accuracy, the profiles along two lines have been analyzed. Along the same lines, the survey was repeated in two times by using both GPR models. The accuracies of models were different based on depth of utility objects and other properties. In general, the utilization of GPR improves and eases the data processing and outputs interpretation. GPR can also minimize the time consumption during data collection. Furthermore, the rising technology of survey instruments makes GPR as the best solution for utility survey mapping application regarding time-consumption and reliability of the results.

In order to introduce GPR to user, for further study it is recommended to study on:
i. Digital image processing for better interpretation of GPR image
ii. The 3D utility mapping application from the usage of GPR
iii. Enhance the calibration technique of GPR through upgrading the existing test base with respect to the accuracy of instruments

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