CALIBRATION FACILITY FOR ANALYSING LOCATIONAL AND DETECTABILITY ACCURACIES OF GROUND PENETRATING RADAR

Siow Wei JAW and Mazlan HASHIM
Institute of Geospatial Science & Technology, Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor Darul Ta'zim, Malaysia.
Tel: +6(0)-7-555-7661; Fax: +6(0)-7-555-7662
E-mail: swjaw@utm.my; mazlanhashim@utm.my

KEY WORDS: Calibration, test site, ground penetrating radar, locational and detectability accuracies

ABSTRACT: Underground infrastructure mapping is an engineering practice that often used for acquiring the as-built information of the buried infrastructure at the urban and suburban areas. It is crucial to acquire the as-built information of these underground infrastructures because this information is constructive for sustainable development of the urban underground land, especially when there are increasing demand of housing and infrastructure in today's era. As a result to this circumstance, majority of the urban underground land has been expropriated to different categories of buried infrastructures (e.g.: utility features, tunnels, transportation, etc.) as a final frontier for urban development. Securing the as-built information of these underground infrastructures is hence substantial for the urban infrastructure planning in the future. Therefore, the aim of this paper is to demonstrate the usefulness of a calibration test site for analysing the locational and detectability accuracies in urban infrastructure mapping. In achieving this, the design of the calibration test site incorporates the needs and requirements of the mapping industry in order to build a better mapping practice in current engineering sectors. All the details of the design and implementation of the calibration test site for analysing the locational and detectability accuracies are specified in this paper. Due to its well-designed structures, including the arrangement and alignment of the buried utilities, this calibration test site can serve as the medium for correlating the underground infrastructures with the real world geophysical anomalies with no doubt. It is hence practical and profitable for geotechnical and applications, civil and environmental engineering studies, mining exploration as well as archaeological surveys. Thereby, such testing site is certainly has the potential to provide unlimited contributions to the advancement of engineering sectors in the future, particularly in the field of underground infrastructure mapping for ensuring the sustainable development of urban underground land.

1.0 INTRODUCTION

Many urban underground infrastructures such as the utility pipelines were buried since Victoria's times, and has come to the end of their practical life and should be replaced or repaired. The maintenance of these infrastructures usually takes time since some of these infrastructures were buried in older cities for more than 150 years ago (Gethin et al., 2007). The maintenance work has not been completed, yet the installation of new infrastructure is happening at the same time due to urban expansion and booming of new communication technologies. With an urgent need for the records of the buried infrastructure's location by the utility owners, contractors or urban planners, it has promoted the obligation to conduct a thorough research for the purpose of underground infrastructure mapping using non-destructive testing (NDT) inspection tools. In doing this, the best way to understand the scanning theories and formation of data of these NDT inspection tools are through a field-based testing model or site.

However, there is still lack of field-based testing model or site which allow absolute calibration for testing the performance of the NDT inspection tools, such as GPR, electromagnetic locator (EML), etc. that commercially available for current underground infrastructure mapping industries. At present, underground infrastructure mapping are generally done using a selected NDT inspection tool with relative calibration using the parameter which pre-set in the system itself. Most of the practitioner will neglect to conduct real time absolute calibration for knowing the locational and detectability accuracy of the inspection tool. This is because the calibration of NDT inspection tool in a live carriage is very expensive and involves complicated procedures, particularly at the area where the ground condition are inhomogeneous. As such, the circumstance of "hit-and-miss" affairs which causing loss of money, property and even lives usually occurs during the pipeline maintenance and installation excavation works. Moreover, there is risks of "vulnerable" errors for locating the absolute position of the buried features and creates high uncertainties of buried utilities safety leading to pipeline damages by using the uncalibrated NDT inspection tools for underground infrastructure mapping. In this regard, performing underground infrastructure mapping using uncalibrated NDT inspection tool is actually spending public monies and threatens public safety.

For this reason, a well-designed field-based testing model or site is critically needed by current mapping industry. Until now, only several test sites had been built for studying the mechanism of GPR or others NDT inspection tool in detecting and locating buried infrastructures, particularly the buried utility pipelines. However, the absolute field-based calibration test site for testing the performance of GPR system in terms of its detectability and locational accuracy is not establish yet in current mapping industry. There are no facility for absolute calibration of NDT inspection tools such as GPR for investigating its locational accuracy in terms of planimetric position (x, y) and depth (z). Most of the GPR system calibrations are done relatively within the equipment where the system will determine the depth and signal's travel velocity devoid of any assessment. The results obtained from underground infrastructure mapping are hence highly ambiguous and yet the data interpretation is extremely tough and difficult due to uncertainty in securing the as-built information of the buried infrastructures.

In this regard, a field-based calibration test site, which contains of the advantages in overcoming the limitation of current test site, was designed and established in this study. The test site was customized experiments, offering advantages of: (i) homogeneous host material; (ii) flexible structure; (iii) avoid from moisture effects; (iv) known location and fabrication material for buried utilities; and (v) tested locational accuracy and detectability in term of planimetric position and depth (Wan Hussin and Mohmoud, 2011). As such, this absolute calibration test site of known position and surrounding host material composition is currently new in the industry and has no current technological or marketing lead. This test site provides calibration and testing of NDT inspection tool's performance with lesser interferences and higher utility detection accuracy. With the calibration results obtained, the performance of the NDT inspection tool can be assessed. In doing this, it can serve to improve the mapping accuracy and indirectly reduce the municipal budget due to failed excavation caused by mislocation of buried utilities using uncalibrated NDT inspection tool for underground infrastructure mapping. Therefore, such field-based calibration test site is necessary and beneficial to the surveyors, engineers, GPR operators, utility companies, government agencies, agencies in statutory bodies, software or hardware developer, researchers or academicians.

2.0 NATIONAL CALIBRATION FACILITIES

Majority of the infrastructure, particularly the utility pipelines (e.g.: power lines, water mains, sewerage system, telephone lines, and gas pipes) is buried beneath today's street. Most of these supply lines have been buried since long ago, where it has come to the end of its practical life. Trenching or open cut has been the commonly used method to lay these supply lines beneath the streets whenever they require maintenance or repair. Trenching is considered the cheapest solution for installing utility supply lines such as the mains water network, wastewater network in subsurface (Ariaratnam, 2010; Hunt et al., 2014). Allied to this, the engineers or contractor facing the difficulty to fit new utility pipeline within the limited space in the subsurface without complete drawing or plan which depicting connection patterns of utility pipelines in the form of parallel or perpendicular at different depths and the actual position of these utility pipelines being placed. Comprehensive information regarding the accurate position and description of the utility pipelines buried beneath the streets is therefore need to be obtained, for the sake of reducing disturbance to traffic flows and damages to third party's utility pipelines or the environment due to imprecise excavation.

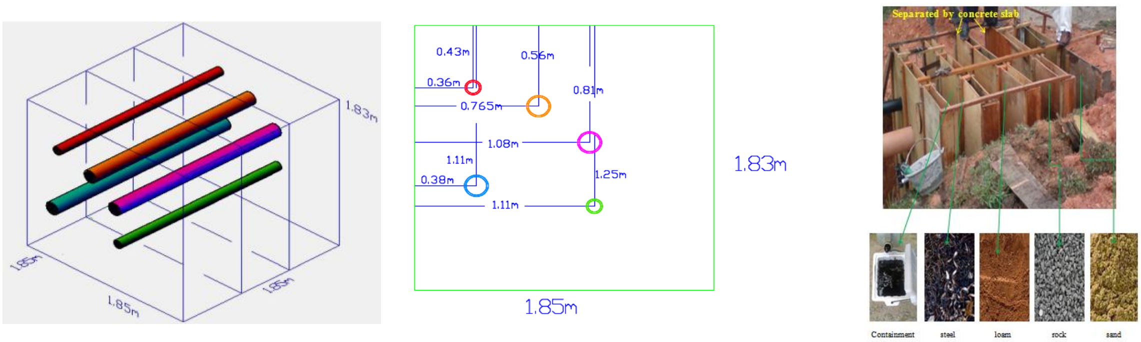
In this context, the best way to understand these buried infrastructures is through a field-based testing facility or test site. A field-based testing facility is always the best way to study and improve the data interpretation of the GPR through conducting experiments on the "laboratory" test model (Wan Hussin and Mohmoud, 2011). It is the most appropriate means for conducting GPR experiment under "laboratory" condition as it is considered the best representation to mimic the subsurface infrastructure in a real environment. Additionally, the calibration for non-destructive instruments in a live carriage is hard to conduct where the ground condition are normally inhomogeneous, hence, a field-based testing facility is the most appropriate way for calibration of NDT inspection tool as it allows calibration to be conducted underground variation of ground condition. With such advantages, field-based testing facility appeared to be more popular and widely used to identify the potential location of the buried utilities based on its known 3D location.

As such, there are many existing calibration facilities in around the world (refers Figure 1), but these facilities are not suitable for calibration of NDT inspection tool because it contains assorted host material composition and high humidity, especially the test site in Tropics like Malaysia which contains tropical climate with humid and wet condition of the soil. The reflection signal of the radar system may affect by high humidity and moisture content of the host material. It may potentially affect the quality of the acquired data and accuracy of final interpretation as well. Current underground infrastructure mapping industry requires a calibration facility which is free from signal interference by heterogeneous host materials and high contents of soil moisture. This calibration facility is urgently needed to solve the problem of mislocation of buried infrastructures during excavation work for infrastructure maintenance and rehabilitation project.

Figure 1. Some of the test site that available on the market

3.0 CONSTRUCTION WORK FOR CALIBRATION TEST SITE

A calibration site composed of dimension of 1.85 x 1.85 x 1.83 metres was established in this study as illustrates in Figure 2. The test site contains of five different sizes utility features that commonly used for water supply, electricity, gas, and sewerage. This test site was selected to build on a slope near a vacant land. As this is a calibration site, the arrangements of the utility feature are deliberately designed to superimpose on one another. With such unique design, it can represent the actual civil engineering structure in the real world which crowded with a complex network of various pipelines. This will allow the actual civil engineering structure and the geophysical anomalies in the real world to be correlated with no doubt during research.



(a) 3-D view (b) Side view (c) Compartment structure of the test site with its host material

Figure 2. Design and structure of the test site

Additionally, it is also worth mentioning the unique design of this test site where it divided into few compartments for composition of homogeneous host material in each compartment. As seen in Figure 2 (c), these compartments are separated by a concrete slab with 0.12 m thickness to avoid mixing of host material as inhomogeneous host materials will complicate the detection of target in a radargram and influence the signal reflection of the target (Orlando and Rui, 2002; El-Mahallawy and Hashim, 2013). The content of these host material is changeable according to personal preferences to facilitate research purposes as the user has their own requirement in their research. Only the design of this proposed test site can satisfy this requirement.

Throughout the establishment of this test site, the sequence of work is similar from excavation of ground, laying pipe and backfilling. After laying pipe and backfilling, the test site is covered by concrete pavement. The standard colour code for utility was used to mark at the concrete pavement to indicate the types of buried utilities and assist buried utility identification in the future. After that, Global Positioning System (GPS) survey was took place to determine the planimetric position of the each buried utility using real-time kinematic (RTK) high precision surveying positioning. By using network-based RTK based on constant GPS reference station for supporting carrier phase positioning, centimetre-level position can be obtained through combing and interpolating the measurement from a fixed network of reference station. These positioning results were thereafter used as the in-situ positioning measurement for validating the location results obtained using commercially available GPR system. Subsequently, the final stage for the construction work was fixing the drainage system to avoid stagnant water in the test site.

4.0 RESULT AND DISCUSSION

4.1 Layout and design of the test site

The layout of the test site that established in this study is shown in Figure 2 (a) and (b). Based on the design of the test site, five utility features that typically used by the utility owners were buried in the test site with variation depths. The positioning details of each buried utility are shown in Table 1.

Table 1. Location details of the buried utilities

Types Of Utility	Materials	Diameter (m)	Position (m) X	Position (m) Y	Depth, Z (m)
Gas	Medium Density Polyethylene (MDPE)	0.100	626564.150	172595.469	0.430
Water	Ductile Iron (DI)	0.100	626564.189	172595.532	0.765
Sewerage	Clay	0.150	626563.899	172595.168	0.560
Water	Mild Steel (MS)	0.150	626563.662	172594.962	0.810
Electric	Polyvinyl chloride (PVC)	0.150	626563.685	172594.985	1.250

4.2 Advantages of the calibration test site

Referring to Figure 1, there are many existing calibration facilities for the purpose of underground infrastructure mapping. However, these existing calibration facilities still consist of many limitations which influence the signal penetration of the NDT inspection tools. For this matter, a better calibration site for overcoming the shortcoming of the existing calibration facilities was designed and established in this study. This calibration test site was established to eliminate most of the environmental factors which may influences the NDT inspection tool signal penetration and to avoid unnecessary clutters. This test site is newly built in Malaysia, with the intention to mimic current underground infrastructures. It is unquestionably distinct from other testing facilities as it has the advantage, as shown in Table 2.

Table 2. Advantages of proposed calibration test site.

No.	Advantages	Description
i.	Better test site function	This test site is suitable for calibration of all frequencies GPR system and NDT inspection tools that available on the market. It is beneficial for understanding the operation of the NDT inspection tools, particularly the GPR for underground and geotechnical applications.
ii.	Specially design	The arrangement of the utility features in the test site is deliberately designed where it is superimpose on one another. With such design, it can represent the actual civil engineering structure in the real world as the underground spaces now is congested with variation networks of utility pipeline. In addition, there are five compartments that filled with homogenous soil materials in this test site aiming for research work regarding soil properties and beneficial for subsurface based research.
iii.	Absence of interferences	This test site is built at the area that absence of interferences, especially from cultural interferences (e.g.: electrical cables, radio transmitters, fences, vehicles or building).
iv.	High accuracy:	Locational and detectability accuracy of the test site is being investigated as mentioned in previous publication (Jaw and Hashim, 2013). The results were validated by known planimetric position (x, y) and depth (z) of the buried

		utility features in order to study the performance of GPR system in terms of its detectability and locational accuracy. As such, the GPR detection accuracy ambiguity in the mapping industry was then can be clarified.
v.	Absence of buried objects	There are no existing utility pipelines available in this test site. This can avoid confusion from interferences from the reflected signal of the untargeted objects.
vi.	Away from water sources	The soil materials in this testing site are away from groundwater sources and rainwater. A cement cover is built to protect these soil materials from groundwater seepage. The host materials are thus always in the dry condition and good for calibrating any frequencies NDT inspection tools.
vii.	Commercial Potentialities	The uniqueness design and structure of the test site also allow optimization and suitable for conducting various experiments relating to underground utility mapping. This test site thereby opening business opportunity through providing calibration services for all NDT inspection tools, such as GPR with frequency ranges of 100 MHz to 1 GHz, pipe cable locator, closed-circuit television (CCTV), sewer scanning and etc. (Hao et. al., 2012).

4.3 Validation of established calibration test site

The overarching aim of this testing site is to assist efficiently in facilitating and optimizing the maintenance and rehabilitation of utility pipelines by means of precise utility detection and excavation. For overcoming all the inherent limitations that currently experience by most of the NDT inspection tools, this test site with unique design of the structure was built, allowing further research in solving some targeted problems which hamper the advances of NDT inspection tools to be a mature technology. Through incremental improvements, perhaps these NDT inspection tools, especially the GPR can become an underground close-range sensing tool which is user-friendly to both non-experts and professional and can provide higher accuracy utility detection to avoid “blind” excavation.

Based on this argument, the proposed calibration test site was tested for its practicality and implication. In achieving this, comprehensive sets of data were acquired using GPR which calibrated using absolute and relative method. For absolute calibration, the calibration of GPR was using the calibration test site that proposed in this study which specifically customized to be used in Tropics to figure out most appropriate signal travel velocity, whilst for relative calibration of GPR, was done with the instrument default calibration parameters without further assessment. Through this comparison, it highlights the importance of good calibration for ensuring the quality of the acquired data. Although similar set data, different calibration methods and parameter will influences the quality of the data acquired, as one can only secure good quality and accurate as-built information of the underground utilities based on right selection of signal’s travel velocity for depth determination during data acquisition (refers Figure 3). In other words, absolute calibration can more accurate for determining the appropriate signal travel velocity as compared to relative calibration. Hence, good calibration is definitely significant for securing reliable as-built information of the buried pipelines for city’s infrastructures planning and reducing the “vulnerable” errors that contributing inaccurate final interpretation of utility data.

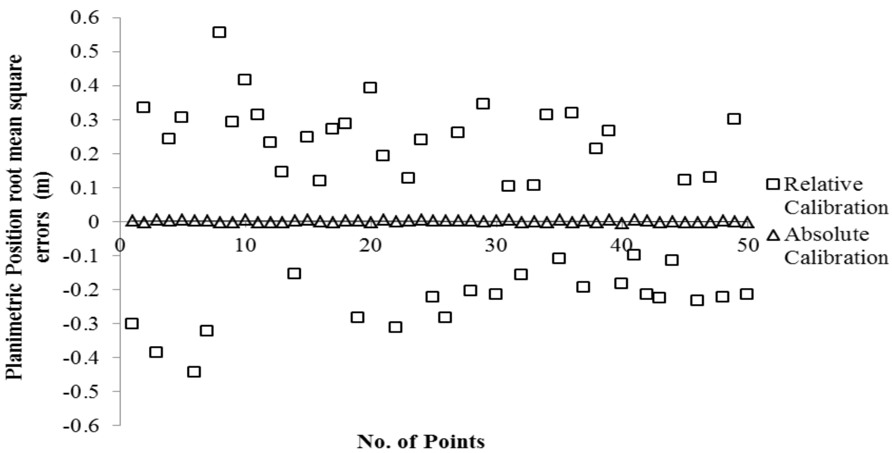


Figure 3. Planimetric position (x,y) root mean square errors distribution graph

5.0 CONCLUSION

A uniquely designed calibration test site was established in this study to mimic the current real civil infrastructure in the subsurface for understanding the locational and detectability accuracies of the NDT inspection tools, especially the GPR. This is because GPR is now the most efficient NDT inspection tools for geophysical investigation such as mapping the superficial bodies for determining the position of these buried objects (Enes et al., 2010; Lester and Bernold, 2007).

For this reason, a well-established field-based testing model or site is crucially needed by current underground infrastructure mapping industry to test the performance of these underground close-range sensing tools for calibration and research purposes. The goal of designed for this testing site is thus intended to meet the needs of the urban environments for underground investigation applications in engineering survey, civil engineering, archaeological studies, geotechnical inspection and mine exploration. With its unique design, the output observed by the equipment can compare with the output measured from the known measurement test site. As a conclusion, the test site established in this study is opening new commercial market for research and development of NDT inspection tools for users which required reliable and precise as-built information of the buried infrastructures as it promotes better detection accuracy through absolute calibration of NDT inspection tools, especially the GPR system. This is a crucial step in assisting the exaction work for civil infrastructure maintenance and installation.

ACKNOWLEDGEMENT

A special thanks to the Univerisiti Teknologi Malaysia and RDG SUPPLY Sdn. Bhd. for providing the financial and technical assistance given in this study. Thanks also appertain to anonymous for their constructive reviews and comments regarding this study.

REFERENCES

Ariaratnam, S. T., 2010. Survey Questionnaire Results of the Current Level of Knowledge on Trenchless Technologies in China. Journal of Tunnelling and Underground Space Technology, 25 (6), pp. 802-810.

El-Mahallawy, M. S.; Hashim, M., 2013. Material classification of underground utilities from GPR images using DCT-based SVM approach. IEEE Geoscience and Remote Sensing Letter, 10, pp. 1542-1546.

Enes, Y., Sevket, D. and Caner, O., 2010. On the Imaging Application of Ground Penetrating Radar. In: 20th International URSI Symposium on Electromagnetic Theory, Berlin, Germany, Augus16-19, pp. 253-256.

Gethin, W. R.; Hancock, C.; Ogundipe, O.; Meng, X. L.; Taha, A.; Montillet, J. P., 2007. Positioning buried utilities using an integrated GNSS approach. In: IGNSS Symposium, Sydney, Australia, December 4-6.

Hao, T.; Rogers, C.D.F.; Metje, N.; Chapman, D.N.; Muggleton, J.M.; Foo, K.Y.; Wang, P.; Pennock, S.R.; Atkins, P.R.; Swingler, S.G.; Parker, J.; Costello, S.B.; Burrow, M.N.P.; Anspach, J.H.; Armitage, R.J.; Gohn, A.G.; Goddard, K.; Lewin, P.L.; Orlando, G.; Redfern, M.A.; Royal, A.C.D.; Saul, A.J., 2012. Condition assessment of the buried utility service infrastructure. Journal of Tunnelling and Underground Space Technology 28, pp. 331-344.

Hunt, D. V. L., Nash, D. and Rogers, C. D. F., 2012. Sustainable Utility Placement via Multi-Utility Tunnels. Journal of Tunnelling and Underground Space Technology, 39, pp. 15-26.

Jaw, S.W. and Hashim, M., 2013. Locational Accuracy of Underground Utility Mapping Using Ground Penetrating Radar. Tunnelling and Underground Space Technology, 35, pp. 20-29.

Lester, J. and Bernold, L.E., 2007. Innovative Process to Characterize Buried Utilities Using Ground Penetrating Radar. Journal of Automation in Construction, 16 (4), pp. 546-555.

Orlando, J. T.; Rui, S., 2002. Image segmentation by histogram thresholding using fuzzy sets. IEEE Transaction on Image Processing, 11, pp. 1457-1465.

Wan Hussin, W.M.A. and Mohmoud, B. A., 2011. The design of a GPR test site for underground utilities. In: Progress in Electromagnetics Research Symposium, Marrakesh, Morocco, March 20-23, 1864-1867.