A Conceptual Framework for Underground Utility Mapping Accuracy Assessment Using Ground Penetrating Radar

Mazlan HASHIM, Siow Wei JAW, and Samsudin AHMAD, MALAYSIA

Key words: conceptual framework, accuracy assessment, underground utility mapping, ground penetrating radar

SUMMARY

Underground utility mapping is an important engineering practice to acquire the as-built information of the buried utility features. Securing the as-built information of the underground utility features will always be a very important step for the city's infrastructure planning. In this regard, an efficient framework, ranging from marking, scanning, detecting, and extracting the geometric information of the buried utilities before displaying the results on preferable deliverable format is very crucial to ensure accurate data acquisition during underground utility mapping. Therefore, this paper demonstrates a conceptual framework for underground utility mapping accuracy assessment using one of the famous non-destructive testing measuring tools, namely Ground Penetrating Radar (GPR). A field-based model which customized for mimic the typical infrastructure that currently buried in the underground was used to assess the effectiveness of the framework. The mapping methodologies, the best practices data acquisition method and reference procedures for assessing the underground utility mapping accuracy was done at the field-based model. The details of this conceptual framework was defines in this paper. Results obtained proved that, the proposed conceptual framework has presented the locational accuracy of underground utility mapping and introduced the best practice for data acquisition using GPR in order to ensure precise underground utility mapping. With the availability of this conceptual framework, it can correct the improper practices that had been practices by the street-workers during underground utility mapping. Through refinement of this conceptual framework, the proposed framework, hence, has the potential to provide unlimited contribution to the improvement of operating procedures of underground utility mapping. Therefore, the establishment of standard operating procedures for surveying work of underground utility mapping in the future towards development of three-dimensional underground cadastral database is within sight.

A Conceptual Framework for Underground Utility Mapping Accuracy Assessment Using Ground Penetrating Radar

Mazlan HASHIM, Siow Wei JAW, and Samsudin AHMAD, MALAYSIA

1. INTRODUCTION

Underground mapping is important for extracting as-built information of the buried infrastructure, particularly the utility features. Ground penetrating radar (GPR) is well-known as the effective measuring tool for underground investigation, including extracting the geometric information of the metallic and non-metallic utility infrastructures that being buried in the underground spaces. It is one of the famous non-destructive testing techniques that widely used in the underground utility mapping industry for accurately locating the utility pipes or cables. GPR operates in electromagnetic domain that designed principally for locating the targets or interfaces that were buried beneath the city's street or within an opaque structure (Daniels, 2004). As such, it is efficiently used for mapping the utility features that buried in the underground spaces which is invisible to the naked eye without the need for excavation. GPR is now the top non-destructive geotechnical technique that is widely used in the profession of underground utility mapping. Nonetheless, not much attention has been devoted for providing specific standard guideline or operating procedure, particularly in showing the right procedures of mapping and accuracy requirement for utility mapping within the populous metropolitan areas. The street-work for underground utility mapping is often conducted based on street-worker's preferable operational practices and experience.

Moreover, there are many catastrophic accidents due to failed excavation being reported in every single year. As such, these contributed to the ambiguities in knowing the measurement tolerance for so-called the accurate underground utility mapping. Hence, the requirement for precise underground utility mapping is necessary, in order to clarify these ambiguities in the underground utility mapping communities. With this, the intrusive vacuum excavation due to intrusive utility location excavation can be avoided. Furthermore, most of specialists in utility mapping profession are working independently, without following any guideline or standard operational procedures (SOPs) and accuracy requirements for their measurement. For the purpose of solving this issue, a framework for accuracy assessment is needed to be established for this profession to ensure precise mapping works are conducted, to ensure the safety of the operation personal and public (Hong Kong Institute of Utility Specialists, 2011). This standardized framework is always served as the rule of thumb for the underground utility mapping street-work and the basic requirement for ensuring precise underground utility mapping.

Therefore, this paper demonstrates a conceptual framework for accuracy analysis of the commonly practised scanning technique for data acquisition in underground utility mapping using GPR and then the best practise is being introduced based on the results obtained. In doing this, the pre-designed scanning techniques were adopted to acquire data using commercially available GPR system at the test site, which purposely set up for assessing the work of underground utility mapping. Then, the same methodology was used to acquire the data at the selected site in the real-life experiment. Thereafter, the accuracy of each scanning technique was assessed based on the accuracy (root-mean-square errors) and target detectability for selection of the best practise data acquisition technique. The research hypothesis set forth that GPR scanning approaches during data acquisition post significant effects to the accuracy of the target identified and the locational accuracy (x, y, and z). This information is the basic criteria for developing a conceptual framework for underground utility mapping which is crucially essential to ensure the street-work for underground utility mapping is conducted safely to avoid third party's pipeline damage, injury or even fatality from befall on those street-workers.

2. UNDERGROUND UTILITY MAPPING FRAMEWORK

A framework for underground utility mapping is a standardized guideline or SOPs in conducting any surveying related activities, as well as to standardize the practises for precise utility detection and localization related matters. It is, hence, important guidance and reference for the street-workers such as land surveyors to conduct any civil engineering, surveying or excavation related task. This is to ensure confident and precise utility detection and localization during underground utility mapping. As such, the local authorities such as the American Society of Civil Engineers (ASCE), the Department of Survey and Mapping Malaysia (JUPEM) and Mapping the Underworld of UK (MTU) are given the responsibility to produce underground utility mapping related standardized guideline or SOP (Department of Survey and Mapping Malaysia, 2006). In this series of standard guidelines provided by each country's local authorities, it contains all the practical procedures for utility detection and localization. The content to include: (i) data acquisition planning, preparation and calibration; (ii) operation personnel and equipment selection for investigation work; (iii) accuracy requirements; (iv) display results on the map and technical report preparation and its its deliverables format, and (v) final assessment and verification. A straight forward and easy-to-follow SOP is produced to facilitate the work of all the specialists from contractors to engineers. From here, all the utility mapping specialists are no longer working independently because this standardize SOP can unify all specialists in the current market and train them to become world class professionals.

2.1 Data Acquisition Planning and Preparation

The street-worker needs to obtain information regarding the underground infrastructure, such as types of features, its size or dimension, location, etc. before any excavation. The accuracy of the information needs to be confirmed to avoid any occurrences for catastrophic damages of buried utilities during excavation. For this reason, the data that collected from related parties need to be checked by in-situ inspection in order to minimise the risks of damaging the existing utility features during construction activities. For those relevant parties who involved in submitting information regarding buried utility, they need to update the latest placement of their utility features. For the street-worker, they need to report if there are any deficiencies in the utility record which discovered during excavation. This is because the countermeasure for precise utility mapping is necessary to reduce the intrusive vacuum excavation in any of the construction work for underground utility installation, maintenance and rehabilitation.

2.2 Operation Personnel and Equipment Selection

Most of the street-work for underground utility mapping is done by skilled operators using appropriate equipment and methods selection. The work is done according to operator's experience without assessment in term of it accuracy, appropriateness, etc. Therefore, the work is controversy amongst the users and has become an argumentative issue within the industry. The well-written SOPs are required for ensuring the appropriate selection of operation personnel and equipment for every underground utility mapping projects.

2.3 Accuracy Requirements

The as-built utility data acquired from underground utility mapping are categorized into four data quality level (i.e. Quality Level A to D). The quality level A data consists of the highest accuracy and the accuracy decrease from quality level A to D (refers to Figure 1). However, among all the documentation that reporting the accuracy requirement for underground utility mapping, only accuracy for quality level A utility data is specified as $\pm$ 10 centimetres (cm) for vertical and horizontal direction. The accuracy for others quality level data are not specified (American Society of Civil Engineering, 2002; American Association of State Highway and Transportation Officials, 2004; Department of Survey and Mapping Malaysia, 2006). This accuracy requirement is being used by the stakeholders for preparing the results obtained from underground utility mapping in different deliverable formats either digital or hardcopy utility map.

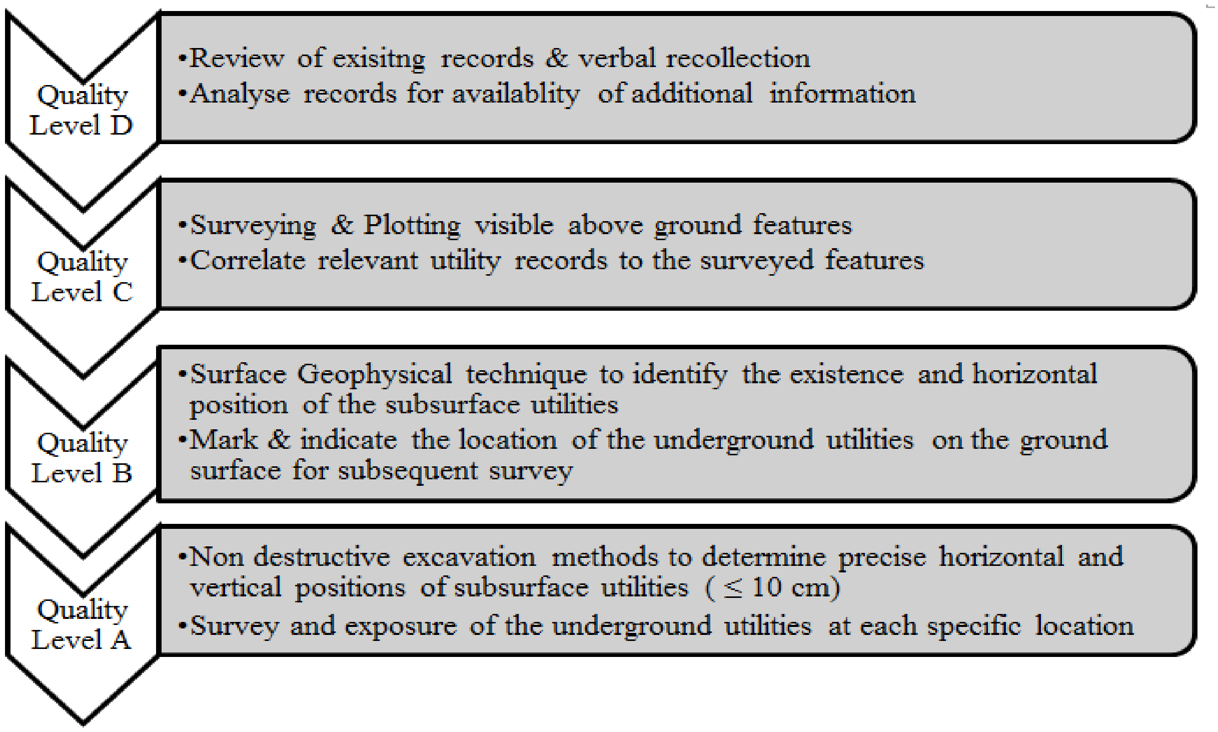

Figure 1. Utility Data Quality Level (Source: Jaw and Hashim, 2013)

2.4 Format of Deliverables

The main deliverable for underground utility mapping is either hardcopy or digital utility map, which contains utility data attribute in plan view with different indicated quality level. When plotting the utility map, the quality levels of the data are annotated with different cartographic elements for demonstration of vertical and horizontal separation between the features. In preparing the utility map, the stakeholders need to follow the requirement set by the each local authorities department, in order to facilitate data retrieval and reference. Subsequently, a centralized national underground utility database is developed and maintained by related authorities department in cooperation with government or private sector utility agencies based on all the utility data attributes provided by different parties from the industry (Jamil et al., 2012). By having such a platform for documentation of as-built information of the buried utility features, the adverse effects due to poor utility location and management, design, construction, as well as maintenance which may potentially lead to third party's utility damages, injuries, properties damage and even fatality are, hence, can be reduced.

2.5 Final Assessment and Verification

For each successful underground utility mapping, the data need to be shared among all the parties within the industries. This as-built information of the buried utility features is essential for surveyors, utility owners, contractors and even street-workers for the planning their task during utility feature maintenance and installations. As such, all the data submitted to the centralized national underground utility database need to have quality inspection regularly, to ensure the data quality achieved the standard set by the local authorities department. In this context, 5% samples from the project and 1% samples were taken from on-site will undergo quality inspection and check by surveyors during the as-built survey (Hong Kong Institute of Utility Specialists, 2011). If there is new construction of utility feature maintenance and installations, the utility owner need to update the latest condition of their utility feature when necessary to ensure that the as-built information of their utility features is always up-to-date.

3. MATERIAL AND METHODS

The practicable degree of the conceptual framework proposed in this study for assessing the underground utility mapping accuracy was assessed by the experiments conducted under laboratory condition. In doing this, the experiments were set up at the calibration test site which specifically built for understanding the scanning mechanism of ground penetrating radar and pipe cable locator. In this calibration test site, there are a total of nine metallic and non-metallic utility features being buried in different depths of 1.15 to 2.37 metres (m) in fixed position and homogenous backfill soil medium. More elaboration (e.g.: buried depth, position, utility feature's material, etc.) regarding the buried utility features in the calibration test site were summarised in Table 1, and the arrangement of the utility features are shown in Figure 2.

Table 1. Details of the utility features buried in the calibration test site

No.	Details	Diameter, Ø (m)	Buried Depth (m)	Material Type
1	Water Pipe	0.15	1.78	Ductile Iron (DI)
2	Water Pipe	0.30	1.15	Mild Steel (MS)
3	Gas Pipe	0.18	1.82	High-density Polyethylene (HDPE)
4	Gas Pipe	0.15	1.59	Medium-density Polyethylene (MDPE)
5	Electrical Cable	0.24	1.47	Polyvinyl Chloride (PVC)
6	Electrical Cable	0.09	1.45	Polyvinyl Chloride (PVC)
7	Sewerage Pipe	0.15	1.73	Mild Steel (MS)
8	Sewerage Pipe	0.23	1.93	Clay
9	Water Pipe	0.30	2.37	Clay

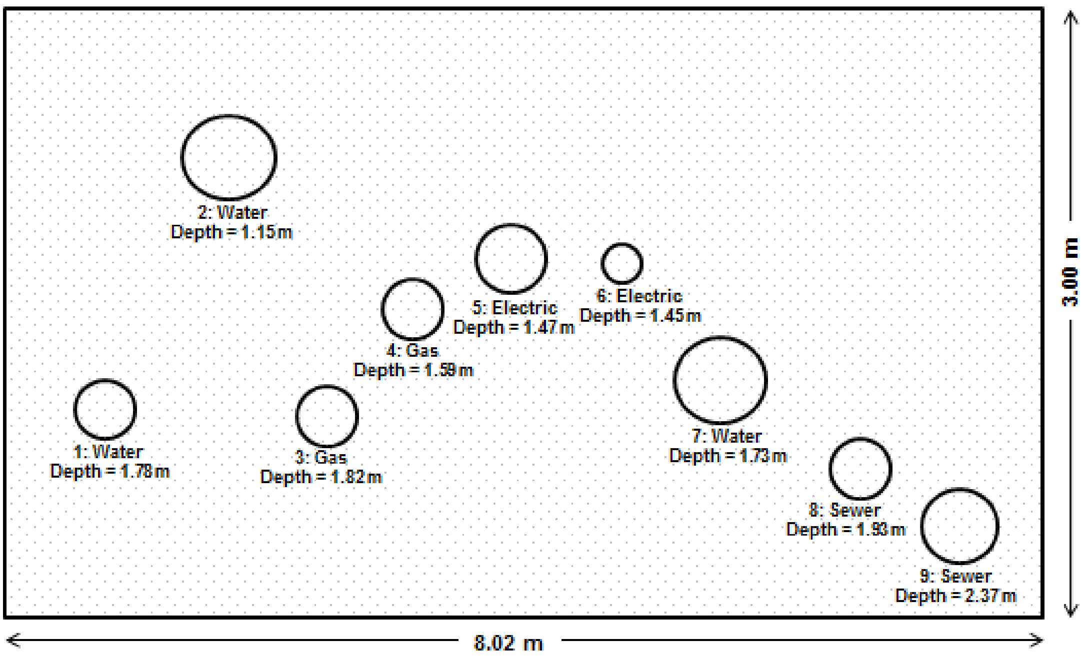

Figure 2. Buried arrangement of the utility features in the calibration test site

In order to include the best practise scanning technique for data acquisition in underground utility mapping using GPR in the framework, two commonly used data acquisition techniques were assessed in this study. These scanning technique for data acquisition, namely: perpendicular-to-pipe and along-pipe scanning was adopted to scan the calibration test site, acquiring comprehensive sets of data with selected GPR system during the dry season as data acquisition done during raining season will affect the quality of the data obtained. Thereafter, the acquired data were pre-processed by removing the signal start time, background noise generated by the ground wave, filtering unwanted echoes due to high frequency speckles and applying linear gain to produce better focus and visualization imagery. After the pre-processing steps, the imagery acquired by selected GPR system was ready for final interpretation to identify the genuine reflection of the targeted features (i.e.: buried utility features in the calibration test site). In this context, the genuine reflections of the utility features are normally located at the bottom of the image while the spurious reflection generated by the non-targeted features and influenced by poor site condition are located at the upper part of the image (Al-Nuaimy et al., 2000). To what extend should the processing work to go beyond is mainly depending on one's opinion, experience and ultimately, this has become an individual's assets. In this sense, accurate interpretation of the image is, hence, the token for having a good result. Lastly, the best practise data acquisition technique was selected from these techniques that gave the best accuracy.

4. RESULTS AND DISCUSSION

In this study, 30 sampling points were selected from each respective scanning using the two data acquisition techniques to compute the overall accuracy. From this achievable RMSE computation, the performance of the scanning technique was assessed.

Through this assessment, it was found that the along-pipe scanning, which is seldom being used for data acquisition in any underground utility mapping project, was performing well. As refers to the Table 2, it shows that the achievable mapping accuracy using along-pipe scanning is the best compared to perpendicular-to-pipe scanning, which has been widely used within the mapping industries. Whilst for the signal penetration depth, the penetration depth for the signal is less than 2 m although the data acquired during the dry season. This is assessed based on the deepest utility features which can be detected. However, all the obtained results are only for reference, the results will be varied in accordance to a different site condition (e.g.: soil moisture, soil medium for signal penetration, etc.). Moreover, the testing was only conducted in laboratory condition; further real world testing is needed for refinement of the obtained results.

Table 2: Results obtained from RMSE assessment

Scanning Technique	**Target Detected**	**RMSE (m)**		**Signal Penetration Depth (m)**
		Planimetric Position (x, y)	**Depth (z)**	
Perpendicular-to-pipe	5/9	± 0. 104	± 0. 106	1.82
Along-pipe	7/9	± 0. 084	± 0. 080	1.90

As evident in recent works of Jaw and Hashim (2013a), Jaw and Hashim (2013b) and Jorge et al., (2010), they have highlighted that best practise data acquisition technique during underground utility mapping is the key parameter to determine good achievable accuracy (Jol, 2009). In their work, they also proved that the scanning orientation is one of the major effects to influence the quality of the data obtained during underground utility mapping. For this reason, having a framework is efficient in bring awareness to the operation personnel where the data acquisition technique shall not be simply adopted for underground utility mapping without assessment as it may affect the overall mapping accuracy and the quality of the data obtained for their projects. The worst is that, improper underground utility mapping may lead to the issue of "blind" excavation which leaving behind many "dry hole", during the construction works and damages of third party's utility features.

5. CONCLUSION

The focus of this paper is to present a conceptual framework which assessing the locational accuracy for underground utility mapping, besides introducing the best practise for data acquisition using GPR system. With regard to this, results of this study presented locational accuracy of the two frequently practised scanning technique for data acquisition in the underground utility mapping industries. The performance of the scanning techniques in data acquisition for underground utility mapping was assessed, and the best data acquisition scanning technique was recommended based on the locational accuracy acquired in this study. Results obtained in this study, contributed to the indication of urgent requirement on the establishment of SOPs for underground utility mapping in the near future as it shows all the methodologies, best practices and reference procedures for underground utility mapping which is beneficial for fostering a safe and healthy working environment to the street-workers during the construction works for utility maintenance and installation.

ACKNOWLEDGMENT

This article is part of the larger project funded by E-Science Fund, Ministry of Science, Technology & Innovation, Malaysia. We acknowledged Dept. of Survey and Mapping Malaysia for the GPR test-bed facility. Assistance of RDG Supply Sdn. Bhd. is also acknowledged.

REFERENCES

Al-Nuaimy,W., Huang,Y., Nakhkash, M., Fang, M.T.C., Nguyen, V.T. and Eriksen, A., 2000, Automatic Detection of Buried Utilities and Solid Objects with GPR Using Neural Network and Pattern Recognition, Journal of Applied Geophysics, 43, 157-165, Elsevier.

American Association of State Highway and Transportation Officials (AASHTO), 2004, Right of Way and Utilities Guidelines and Best Practices, Strategic Plan 4-4, U.S., American Association of State Highway and Transportation Officials.

American Society of Civil Engineering (ASCE), 2002, Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data, 4-6, New York, ASCE Code and Standards Activity Committee (CSAC).

Daniels, D.J., 2004, Ground Penetrating Radar. (2nd ed.), 625-634. 726, London, UK, Institution of Electrical Engineers.

Department of Survey and Mapping Malaysia (JUPEM), 2006,.Standard Guideline for Underground Utility Mapping, 4-7, Malaysia, Department of Survey and Mapping Malaysia.

Hong Kong Institute of Utility Specialists, 2011, Work Procedure for Utility Mapping by Non-destructive Methods, 1-12, Hong Kong, Utility Training Institute.

Jamil, H., Nomanbhoy, Z. and Mohd Yusoff, M. Y., 2012, Underground Utility Mapping & its Challenges in Malaysia, FIG Workshop Week 2012, Rome, Italy.

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

Jaw, S.W. and Hashim, M., 2013b, Urban Underground Pipelines Mapping Using Ground Penetrating Radar, 8th International Symposium on Digital Earth 2013, Sarawak, Malaysia.

Jol, H. M., 2009, Ground Penetrating Radar: Theory and Application. (1st ed.), 141-172, Netherlands, UK, Elsevier Science.

Jorge, L. P., Slob, E., Robson, S. L. and Leite, D. N., 2010, Comparing Detection and Location Performance of Perpendicular and Parallel Broadside GPR Antenna Orientation, Journal of Applied Geophysics, 70, 1-8, Elsevier.

BIOGRAPHICAL NOTES`

Prof. Sr. Dr Mazlan Hashim is currently Director of the Institute of Geospatial Science & Technology (INSTeG) and Professor of Department of Geoinformation in Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia. He is a professional member of IEEE and IEEE transactions of Geoscience & Remote Sensing; Malaysian Royal Institution of Surveyors (MRISM), International Association of Hydrology Scientists. He is also the exco of Institution of Geospatial and Remote Sensing Malaysia (IGRSM). Currently, he is Principle Investigator (PI) of Research on Assessment of Subsurface Infrastructures Condition Using Image-Based Nondestructive Testing System. He was also PI for more than 15 research projects in geospatial sciences and related applications including few key international projects. He has published over 200 articles in SCI journals and various scientific articles in book chapters; apart won various international and national academic and innovation awards.

Dr. Jaw Siow Wei is currently a researcher in Institute of Geospatial Science & Technology (INSTeG). She is a student member of American Society of Civil Engineers and Institution of Geospatial and Remote Sensing Malaysia. Currently, she is working on research related to subsurface utility mapping and ground penetrating radar image processing. With the experience in remote sensing and digital image processing, has led her to publish numbers of ISI-cited publications in journal and indexed proceeding. During her doctorate study, she has also won various awards such as best paper presenter (JSPRS Award) in 32nd Asian Conference on Remote Sensing (ACRS 2011) and silver medal in 12th Malaysia Technology Expo 2013 (MTE 2013) and Industrial Art & Technology Exhibition (INATEX 2012).

Mr Samsudin Ahmad is currently a senior lecturer at Department of Geoinformation in Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (UTM). He is an associate member of Institute of Geospatial Science & Technology (INSTeG), UTM. Mr Ahmad has taught surveying engineering, and remote sensing in UTM since 1985.

CONTACTS

Prof. Sr. Dr. Mazlan Bin Hashim
Institute of Geospatial Science and Technology (INSTeG)
Block T06, Ground Floor (01-04-12)
Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
MALAYSIA.
☎ : 07-55 57662 / 019-7173861
🖷 : 07-55 57662
✉ : mazlanhashim@utm.my; profmhashim@gmail.com
Website: http://www.utm.my/insteg/

Dr. Jaw Siow Wei
Institute of Geospatial Science and Technology (INSTeG)
Block T06, Ground Floor (01-04-12)
Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
MALAYSIA.
☎ : 016-3037463
🖷 : 07-55 57662
✉ : swjaw@yahoo.com; swjaw16@gmail.com