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

Mazlan HASHIM, Siow Wei JAW, and Samsudin AHMAD

Institute of Geospatial Science & Technology (INSTeG),
Univerisiti Teknologi Malaysia

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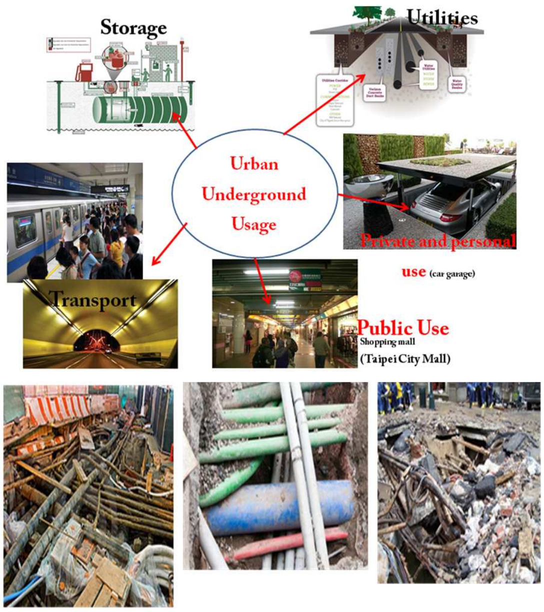
Background



Types of Utility
- water pipe
- Gas pipe
- Sewerage pipe
- Electrical cable
- Telecommunication cable
- Fiber optics

- Rapid urbanization has lead to the expansion of these urban infrastructure.
- limited land area, the urban underground space is increasingly exploited for the purposes of transportation, utilities and even public usage.
- Urban underground are currently congested with various types of infrastructure, especially the **utility pipelines**.
- It is difficult to map these infrastructure under such congestion circumstance as these infrastructure are mostly invisible to the naked eye.

Background (Cont'd)

- Underground mapping is being introduced to scan, detect, and locate the buried infrastructure utilizing non-destructive geotechnical instruments (e.g acoustic energy meter-mining; Crack Detection Microscope-concrete; GPR–underground utility mapping).

- **GPR** - the most popular imaging tool for underground mapping based on its advantages in providing high resolution imagery, fast and economic data acquisition.

Ground Penetrating Radar (GPR)

- Utility Mapping & Detection
- Civil Engineering
- Transport
- Mining
- Geology & Environment
- Archeology
- Forensic & Public Safety

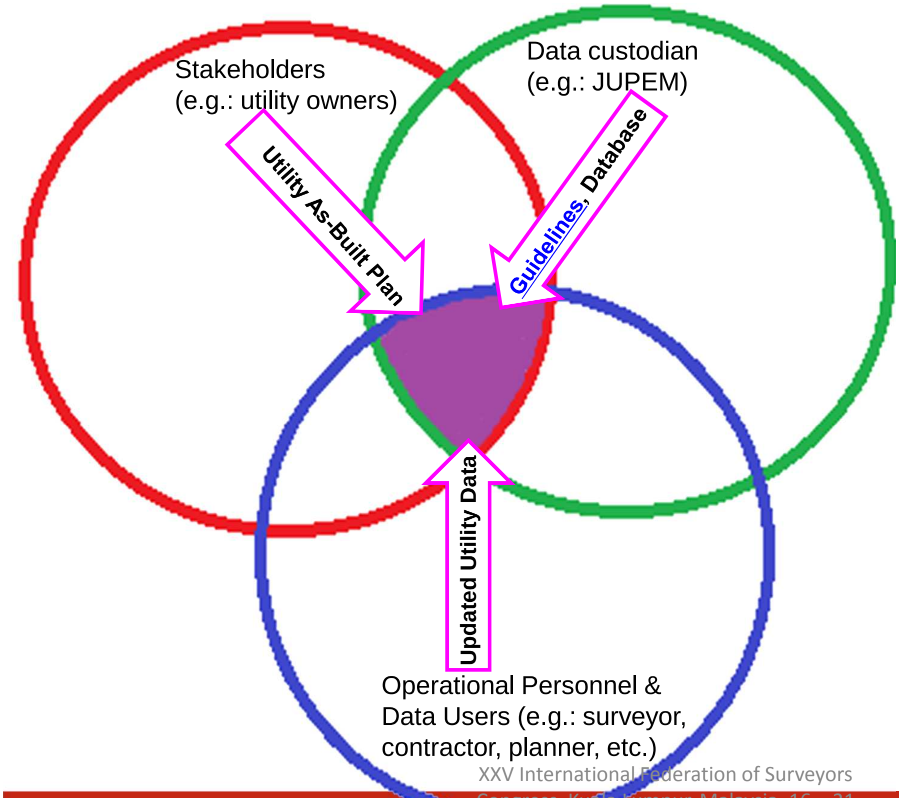
Background (Cont'd)

- At present, only limited utility's geometric properties (i.e.: planimetric location and depth) are being used by stakeholders. It is somehow "underutilize" for understanding utility's radiometric properties.

- Less 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.

- Most of specialists in utility mapping profession are working independently, without following any standard operational procedures (SOPs) or underground utility mapping framework and accuracy requirements for their measurement.

- As such, it has created a gap between engineering and mapping disciplines for understanding the GPR capabilities in underground utility mapping.



Framework:

1. Data acquisition technique (scanning techniques)
2. Data locational accuracy (quality level of data acquired)
3. Equipment calibration & fitness test (Efficiency of each GPR system)
4. Survey Reference
5. Deliverables

Guidelines produced by the Technical Committee for Utility Mapping

Standard Guideline for Underground Utility Mapping **(KPUP Circular 1/2006)**	Guideline for Underground Utility Survey **(KPUP Circular 1/2007)**	Guideline for Survey of New Utilities **(KPUP Circular 1/2013)**
❖ Roles of stakeholders(Utility Providers, Surveyors, JUPEM) ❖ Classification of quality levels (Quality levels A, B, C, D & How utility information can be obtained) ❖ Specifications of underground utility maps (Formatting of the utility map) ❖ Creation and maintenance of underground utility database by JUPEM (PADU)	❖ Guideline for surveyors in undertaking utility survey (provides surveyors with the recommended technique and practice for the execution of utility detection for quality level A and B and sometimes quality level C) ❖ 3 ways of obtaining underground utility information i. Underground detection (non-invasive technique) ii. Survey of surface utility features iii. Survey of utilities during installation	❖ Guideline for survey of utilities during installation i. Utilities in common trenching ii. Utilities in common utility tunnel iii. Utilities within ROW iv. Utilities installed by Horizontal Directional Drilling (HDD)

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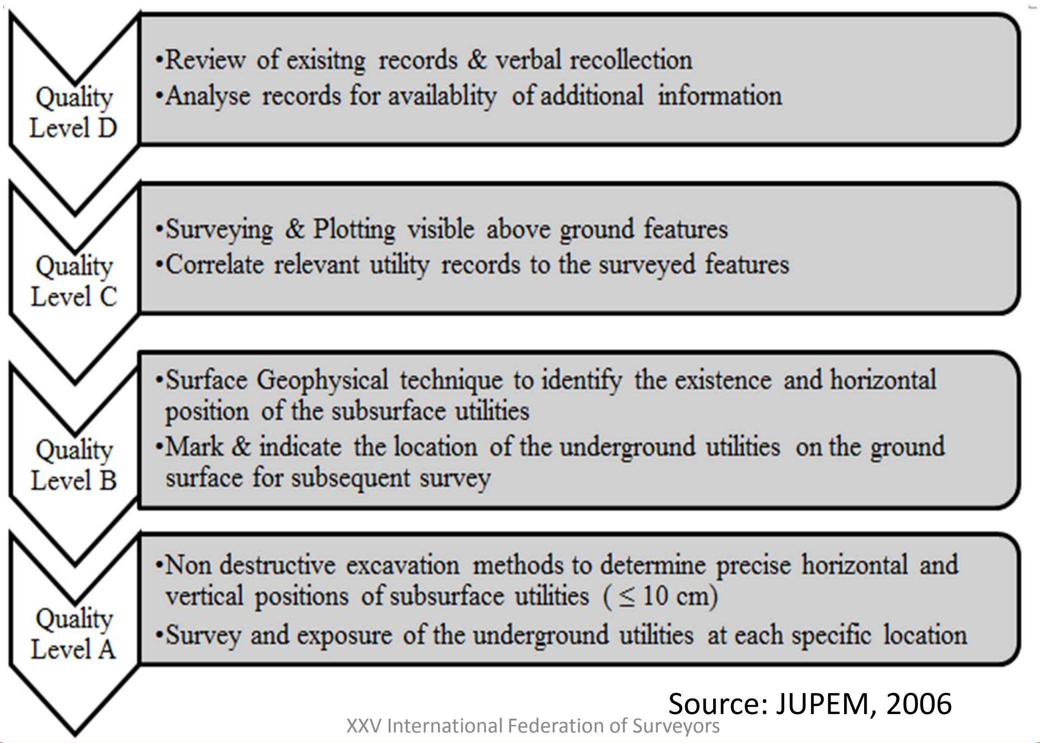

Source: JUPEM, 2006

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Introduction

Mapping the underground

- Securing reliable and complete sets of information for the buried infrastructure is a necessity to ensure urban/cities sustainability (including safety)
- Current industry needs to explore the new capabilities of GPR and attempting to solve the limitation of current technology, in knowing the measurement tolerance for so-called the accurate underground utility mapping.
  - **How to calculate the measurement tolerance for so-called the accurate underground utility mapping?**
  - **Why is it so important to know the measurement tolerance for so-called the accurate underground utility mapping?**

Calculate The Measurement Tolerance

❖ How deep can a GPR measure?

20 wavelengths

Signal wavelength, $\lambda = \frac{c}{f_m \times \sqrt{\varepsilon_r}}$

(Pasolli et al., 2009)

Where,

f_m= 3 x f_{centre}

ε_r= dielectric permittivity of the medium

Example (250 MHz antenna):

f_m= 3 x 250 MHz = 7.5 x 10^8

λ = 0.25 m

∴maximum penetration depth

= 20 * λ

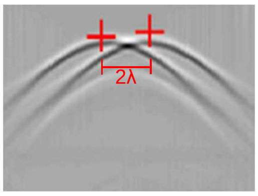
= 20 * 0.25

= 5 meters

o How do I know I can find my targets?

i. For a target to be distinguishable from similar targets:

Answer: 2 wavelength separation
(for horizontally stacked utility)



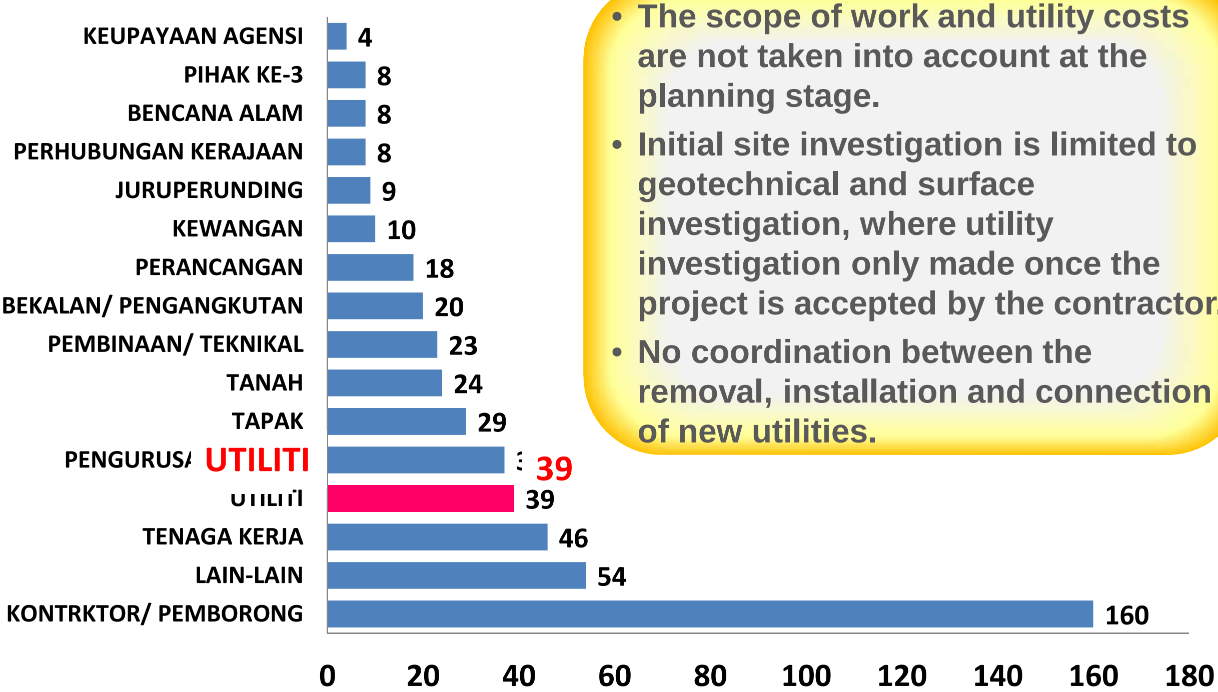
(Jaw and Hashim, 2013)

ii. The accuracy of target depth:
Answer: 0.25 of a wavelength

iii. The smallest target detectable:
Answer: 0.1 of a wavelength

(Mahalewy and Hashim, 2014)

Analysis For Causes of Project Delays



- The scope of work and utility costs are not taken into account at the planning stage.
- Initial site investigation is limited to geotechnical and surface investigation, where utility investigation only made once the project is accepted by the contractor.
- No coordination between the removal, installation and connection of new utilities.

Source: Sistem i-Pantau, ICU JPM, for year 2013 until 31 December 2013.

Objective of the Study

- To demonstrates a conceptual framework for accuracy analysis of the commonly practised scanning technique for data acquisition in underground utility mapping using GPR.

  - To introduce the best practice scanning technique for data acquisition based on the results obtained.

Materials & Methods

i. GPR System Technical Specifications

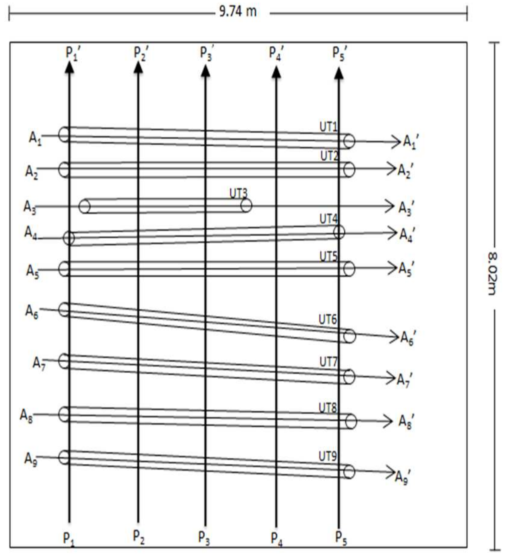
- Frequency: **250 MHz and 700 MHZ**
- Size: **68 X 80 cm**
- Operating system: **Window 2000 Pro/ XP Pro**
- Survey Speed/ scan rate: **9 km/h or 100 scans/second**
- Scan Interval: **2.5 cm**

- Frequency: **250 MHz**
- Size: **31 X 18 cm**
- Operating system: **Linux platform**
- Survey Speed/ scan rate: **128-8192 sample/per trace**
- Scan Interval: **2.5 cm**

- Frequency: **250 MHz**
- Size: **64 X 41 cm**
- Operating system: **Linux platform**
- Survey Speed/ scan rate: **100,000 samples/s**
- Scan Interval: **2.5 cm**

Materials & Methods (Cont'd)

ii. Test bed Description



The arrangement of the buried utility features & scanning direction

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

The descriptions of the utility features

Materials & Methods (Cont'd)

Data acquisition

i) GPR system: IDS DetectorDuo

ii) Scanning Methods: Perpendicular-to-pipe & Along-pipe scanning

Pre-processing

- Remove Start Time
- Background Removal
- Filtering
- Linear Gain
- Migration

Results& Discussion

- RMSE value
- Target detectability
- Penetrative power

Results and Discussion

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

*** Penetration depth= based on the deepest pipe can be detected**

Results and Discussion (cont'd)

- As evident in recent works of Mahalawy and Hashim (2014), Jaw and Hashim (2013a), Jaw and Hashim (2013b) and Jorge et al., (2010), (Jol, 2009) - highlighted that best practise data acquisition technique during underground utility mapping is the key parameter to determine good achievable accuracy.
- The scanning orientation is one of the major effects to influence the quality of the data obtained during underground utility mapping.
- Having a framework (acquisition) is critical operation for underground utility mapping as it is effecting the data quality obtained and overall mapping accuracy.
- 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.

Conclusion

- A conceptual framework which assessing the locational accuracy for underground utility mapping was demonstrated, besides introducing the best practise for data acquisition using GPR system.
- 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.

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Thank you for your attention!

M. HASHIM, **S.W, JAW,** S. AHMAD

Email: mazlanhashim@utm.my

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