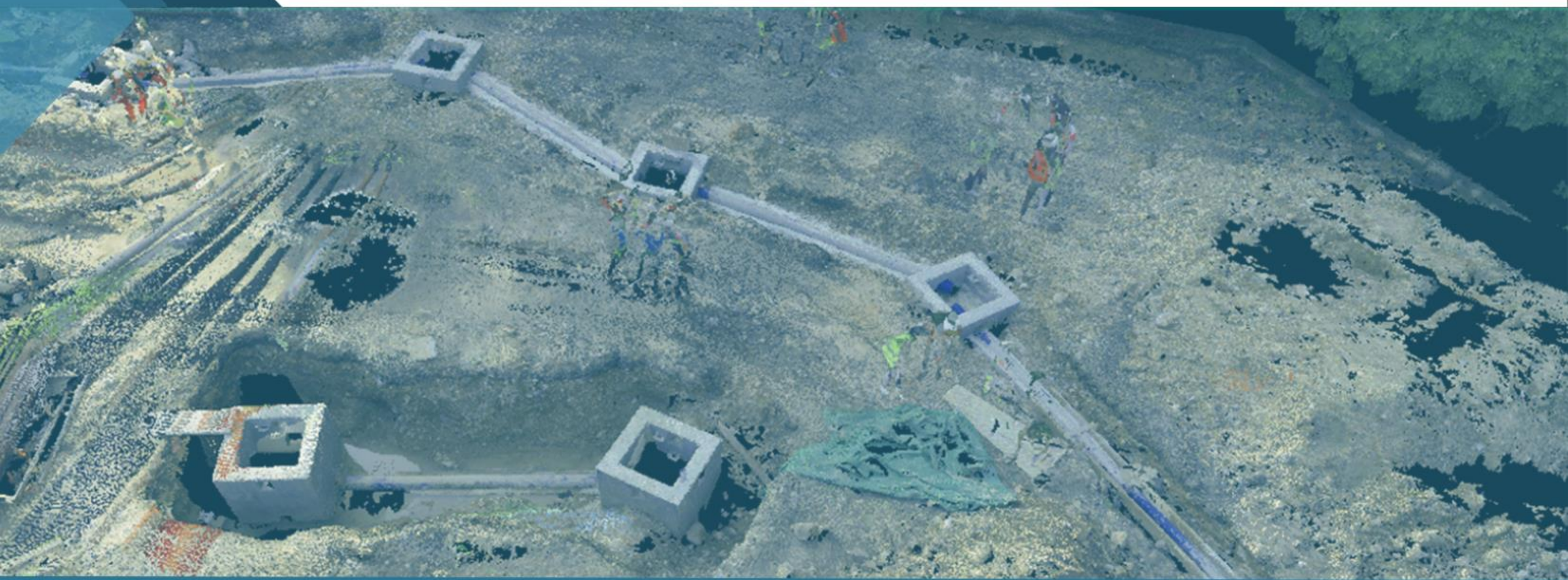
SPECIFICATIONS FOR NONDESTRUCTIVE TESTING, SURVEYING, IMAGING AND DIAGNOSIS FOR UNDERGROUND UTILITIES

1,3 LASER SCANNING SURVEY (VERSION.1)

[NDTSID-UU-1,3]



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SPECIFICATIONS FOR NONDESTRUCTIVE TESTING, SURVEYING, IMAGING AND DIAGNOSIS FOR UNDERGROUND UTILITIES

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Foreword

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LASER SCANNING SURVEY

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A – Acknowledgement to Steering, Technical Workgroup 1,3

This document (1,3) is one of the six specifications prepared for accrediting laboratories/survey companies conducting underground utility surveys. The project team expresses the greatest appreciation and gratitude to the following parties for providing support during the drafting and implementation of this specification.

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B – Background

B1 – History

Laser scanning or light detection and ranging (LiDAR) systems have been used in the construction and surveying industry for reality capturing, progress monitoring and building information modelling. Traditional surveying requires the use of a total station/levelling equipment to acquire the topographic profile of the surveyed sites. As a modern piece of surveying equipment, the 3D laser scanner is capable of providing a rapid survey and large-area monitoring, with a significant improvement in terms of efficiency and coverage, while sacrificing nothing in terms of accuracy. The collected 3D point clouds do not only aid in creating a 2D profile but also 3D digital models, and both can serve the purpose of thematic analysis and visualization of the utilities' size/geometry.

B2 – Significance, Applications and Scope of Specification

B2,1 Significance and application

Underground utilities are the veins of any city. Damage to various types of pipes can be visually inspected and systematically recorded via a number of coding systems published by different agencies. The laser scanning survey method described in this specification covers the history, theories/principles, equipment, field procedures, interpretation of data, and methods for the non-destructive and shallow surface inspection system. It supplements visual inspection by CCTV and manhole survey (LSGI, 2020). The approach suggested in this method for conducting laser scanning is the most commonly used, widely accepted, and well proven. However, other technically sound approaches or modifications to laser scanning may be substituted if technically verified, validated and documented.

The **inspection records** of laser scanning are the major deliverables of surveys aimed at assessing the size/geometry and surface/shallow subsurface conditions, respectively. However, the ways these records are produced based on proper test/survey/diagnostic procedures vary significantly between companies and individuals. Erroneous or incomplete information within the utilities map can mislead users, causing unnecessary damage and exposing the public and workers to danger. Experience and knowledge of the subject area greatly enhance the credibility of the utilities map and, most importantly, help clarify when the test/survey/diagnostic results are uncertain due to site, materials and equipment limitations rather than the Signatory/Survey Officers' abilities. The successful management of the above factors can be summarized in a **4M1E** framework: namely, **M**an/woman, **M**achine, **M**aterials, **M**ethods and **E**nvironment, which can be applied within an accreditation framework following 'ISO/IEC 17025 (2017) General requirements for the competence of testing and calibration laboratories'. In view of the above needs, this document provides a unified specification and standard for laser scanning survey of underground utilities' size/geometry and surface conditions based on 4M1E, which aims to help utility companies, laboratories/survey companies, developers, estate managers, contractors and consultants to maintain consistent standards of UU testing, surveying, imaging and diagnosis.

Apart from visual inspection (LSGI, 2020), laser scanning can evaluate the size, condition of surface or shallow subsurface of the utilities under the right conditions, consistent and reliable interpretation can only be performed by an experienced Signatory/Survey Officer. Such experience can be gained through use of the system and through training courses provided by recognized universities, institutions, various equipment manufacturers or consulting companies.

B2,2 Scope

1. This test method covers the history, theories/principles, equipment, field procedures, interpretation of data, and methods for the inspection of vertical shafts (e.g. manholes) and horizontal pipes (e.g. drains, sewers, water and gas pipes).
2. The approach suggested in this method for conducting laser scanning is the most commonly used, widely accepted, and well proven. However, other technically sound approaches or modifications may be substituted if technically verified, validated and documented.
3. This method does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Laser scanning can be included as one of the surveying technologies used in inspections of underground infrastructure (Fekete et al., 2010; Zlot and Bosse, 2014). With the invention of stationary and portable 360-degree laser scanners, there are two major applications of the equipment: manholes/horizontal pipes and open trench. For manholes/horizontal pipes/culverts, laser scanners can be lowered down into the confined space by using an inverted tripod. Using a rope, winch or remote control, the operator pulls the laser scanner to each manhole location. For scanning of utilities in open trench before backfill, laser scanners can be positioned next to or moved along the trench for scanning various types of utilities. For both applications, data are collected and registered as sets of 3D point clouds. The collected 3D point clouds can then be used to support a range of different manhole condition assessments and as-built records of utilities. For instance, the cross-section of the manholes/horizontal pipes/culverts can be examined with respect to its original design (i.e. comparison of sizes). This technique is deemed to be particularly efficient and practicable, particularly in a confined space, manholes on roads with heavy traffic, or open trench where detail visual inspection or traditional land surveying tools is not possible or inefficient. Also, the remote operation of the laser scanner can also improve the safety of such survey by removing the need for person-entry by the operators/technicians. For open trench environment, laser scanning can be conducted along the pipe run after it is laid and installed and before the final backfill. The collected 3D point clouds can be used for surface reconstruction and digital 3D modelling, which addresses the needs of different end-users.

B3 – Glossary

The glossary can be found in ISO: 17123-9 (2018), and is therefore not repeated here.

B4 – Theories and Principles

B4,1 Laser scanning survey

A laser scanner is capable of collecting a set of 3D point cloud data together with a backscattered value of laser signal strength for each point, which is commonly known as intensity (Wehr and Lohr, 1999). With the aid of Global Navigation Satellite System (GNSS)/Inertia Measurement Unit (IMU), the collected 3D data points can be geo-referenced so that the coordinates of the 3D point cloud can be projected onto a real-world coordinate system. Even without direct georeferencing, the current generation of portable laser scanners can also mosaic and stitch together the point clouds collected in different locations using Simultaneous Localization and Mapping (SLAM) technology (Durrant-Whyte and Bailey, 2006) or other indirect georeferencing methods, such as an iterative closest point algorithm (Besl and McKay, 1992). The strength of the laser backscattering signal mainly depends upon a number of system-related and environmental factors, such as the distance between the laser system and the surveyed objects, the angle of incidence, the atmospheric attenuation and, most importantly, the instantaneous surface condition, which includes variables such as the spectral reflectance, surface roughness and moisture levels (Wagner 2010). The backscattered laser waveform is usually post-processed by extracting the peak amplitude in order to derive the so called 'intensity' value. Most of the commercial laser scanners used for surveying purposes adopt a monochromatic near-infrared (NIR) laser (i.e. 780 – 1550 nm) that permits a high separability of different materials across the NIR spectrum. Apart from its own intensity value, a laser scanner can be equipped with an external optical camera so that each laser point can be embedded with a RGB value, which can further enhance the analytical capability of the collected point cloud.

B4,2 Accuracy

Table 1 recommends the survey accuracies for different measurements.

Table 1 Recommended accuracies for different measurements

Survey method	Measurement	Tolerances
Laser scanning survey (in dry conditions)	Location measurement	± 100 mm
	Levels	± 30 mm
	Relative levels of pipe inverts within the chamber	± 15 mm
	Pipe sizes	± 15 mm
	Box culverts	± 20 mm
	All other dimensions	± 20 mm

All reported coordinates and levels should be represented in HK 1980 Grid coordinates based on HK80 Datum. (The coordinates for N,E are presented as 8*****.***, 8*****.***, relative to the HK80 Datum. Normally, "All levels are referred to HKPD" must be present). The recommended accuracies do not mean to be a specific standard for all sorts of utility survey. The operator should discuss with the client in order to leverage between the accuracy and the resources, depending on the application and the final product. However, an accurate point cloud can enhance the automation and improve the efficiency of the subsequent data processing, such as identification of valves, robust cylinder fitting of the circular pipe, etc.

C – Qualified Personnel

C1 – Personnel

The Signatories and Survey Officers for the laser scanning survey shall meet the personal requirements in Sections C2 and C3 below, respectively.

C2 – Signatory

C2,1 A **Signatory** of a report shall either have:

(i) a Bachelor of Science (e.g. Geomatics/Land Surveying and Geo-informatics) or Engineering (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) degree provided by a recognized tertiary institution plus at least ***three*** years of technical and managerial experience of surveying, within which a period of two years is substantially[1] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[2] of specialization in surveying issued by a recognized organization operating under international standards or qualifications framework level 4 plus at least ***five*** years of technical and managerial experience of surveying, within which a period of three years is substantially[1] related to the subject matter in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline, with at least ***seven*** years of direct technical and managerial experience of surveying, within which a period of five years is directly related to the subject matter in this specification, plus relevant training courses[2] covering the content in this specification.

[1] Direct technical and managerial involvement in 10 test/survey reports in different contracts/works orders.
[2] A typical certificate/diploma shall include all aspects covered in this specification.

C3 – Survey Officer

C3,1 A **Survey Officer** shall normally be supervised by a Signatory having the necessary qualifications, experience and technical knowledge, and shall either have:

(i) a Bachelor of Science (e.g. Geomatics/Land Surveying and Geo-informatics) or Engineering (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) degree provided by a recognized tertiary institution, plus at least ***one*** year of on-the-job experience substantially[3] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[4] of specialization in surveying issued by a recognized organization operating under international standards or qualifications framework level 3 plus at least ***two*** years of substantial on-the-job experience[3] related to the subject matter[4] in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline, plus at least ***three*** years of substantial on-the-job experience[3] related to the subject matter in this specification, plus relevant training course[4] covering the content in this specification, or

(iv) at least ***eight*** years of substantial on-the-job experience[3] related to the subject matter in this specification.

[3] On-the-job direct involvement in 10 test/survey reports in different contracts/works orders.
[4] A typical certificate/diploma shall include all hands-on aspects covered in this specification.

D – Instrumentation

D1 – General

Any suitable lightweight, stationary, portable or hand-held laser scanner is recommended. The laser scanning equipment shall be able to collect a set of 3D point cloud for a panoramic field of view (i.e. 360° vertical and 320° horizontal). Each individual point in the point cloud data shall be recorded with its own intensity value. Also, a colourized (RGB or thermal IR) point cloud is highly preferable, which can be achieved with the aid of an external or an on-board camera(s). In terms of configuration, the equipment shall use a NIR or IR laser (e.g. 830 nm or 1550 nm), supported with an eye-safe, short-range scanning capability (e.g. < 100 m) and a minimum range of approximately 0.6 m or a range recommended by the manufacturer. The scan resolution, including the scan frequency and pulse repetition frequency, should be configured so that a minimum point spacing of 10 mm can be achieved. The range accuracy (per 1 sigma) shall be <10 mm over a distance of 25 m. The laser point density shall be 300,000 points per second or better. The data storage setup shall adopt either an integrated flash drive or an external USB flash drive.

D2 – Equipment calibration

The calibration/verification requirements shall follow Table 2.

Table 2 Specific Calibration/Verification Requirements

Type of equipment	Maximum period between successive calibration/verification	Calibration/verification procedure or guidance documents and equipment requirements
Laser scanner	3 years	Calibrate the laser scanner with reference to manufacturer's requirements. The calibration certificate of a laser scanning device shall contain sufficient information such as distance and angle measurements.
	1 year (Verification)	Procedure: Evaluate the expanded uncertainties of measurement according to the full test requirement described in ISO: 17123-9 (2018), and setup of a baseline with geo-referenced x-, y- and z-coordinates in a field test using a calibrated 2'' total station. Acceptance criteria: If the statistical uncertainties of the measurement are larger than the uncertainties recommended by the manufacturer, a full calibration/repair of the laser scanner is necessary.
	Before each test	The system check procedure recommended by the manufacturer shall be followed.
Other equipment related to this visual inspection survey (e.g. total station, digital level)	1 year (calibration)	Accuracy requirement provided by the manufacturer shall be observed.

E – General Testing and Survey Procedure

Before conducting the laser scanning survey in either manholes/horizontal pipes/culverts as well as open trench, the following steps are recommended and particular procedures are recommended in Table 3:

(a) Initialize the laser scanner on a stable flat surface.
(b) Conduct a trial run of the laser scan on the ground so that the laser scanner is properly collecting data without any mechanical problems.
(c) Make sure that the surveyed object is located within the range limit of the laser scanner.
(d) Make sure that any objects located closer to the scanner than the manufacturer's minimum suggested distance are not captured.
(e) Ensure the quality and completeness of the collected data in 3D point cloud by visualizing the point cloud on-site using a cell phone or a tablet computer.

Table 3 Key points of testing and survey procedures

	Laser scanning survey	
	Manholes/horizontal pipes/culverts	Open trench
Setup	Mount the laser scanner on a cart of an inverted tripod.	Set up the laser scanner outside the open trench and properly place the equipment on a tripod being set up on a stable ground nearby the open trench.
Coverage and point density	Identify a number of laser scanner stations along the site to make sure there is a sufficient coverage and point density for overlapping of point cloud data in the entire site. These laser scanning stations must be within line of sight.	Identify a number of laser scanner stations along the pipe run to make sure there is a sufficient coverage and point density for overlapping of point cloud data in the entire site. These laser scanning stations must be within line of sight.
Reference target and overlap of survey[1]	Place any reflective surveying/ photogrammetric target, if possible, on stable surface, such as wall, concrete surface or the pipe run itself, so that the collected point clouds can be recognized, geo-registered and geo-referenced to a local/projected coordinate system.	Place any reflective surveying/ photogrammetric target on stable surface, such as wall, concrete surface or the pipe run itself, so that the collected point clouds can be recognized, geo-registered and geo-referenced to a local/projected coordinate system. If there is a second visit on another part of the open trench extended from the first visit, make sure that the targets in the first visit are covered and overlapped in the second visit for the sake of keeping continuity of geo-registration and geo-referencing in different visits.
Other objects	Remove any unnecessary object within the manholes/horizontal pipes/culverts	Remove any unnecessary objects within the site.
Weather	-	Not to conduct the survey during or right after a rain event since null returns/data voids may be found.

[1] If necessary, more stringent requirements of the number of control points, check points and tie points, as well as overlap of scanning in different visits may be referred to DSD (2019).

F – Reporting

The report shall include, but not be limited to the following sections:

- Introduction and background
- Site areas, boundary and conditions
- Instrumentation (Section D)
- General test/survey procedures (Section E) and site-specific procedures
- Summary of findings and Survey drawings in point-cloud/CAD/GIS/BIM formats
- Limitations (Section G)
- Conclusions
- Site photos in an appendix
- Record drawing (reference utility plans provided by utility companies and clients)

(a) The collected 3D point cloud should be provided in ASCII, LAS, or E57 data formats, including but not limited to the following fields: x-coordinate, y-coordinate, z-coordinate, intensity and RGB value. The specification for the LAS data format shall follow the latest version published by the American Society for Photogrammetry & Remote Sensing (ASPRS, 2013). In the final report, the date of survey, scanning configuration, 3D point cloud, data processing workflow and final results shall be included. If the point cloud is mosaicked using multiple data scans, the accuracy of the point cloud registration shall be reported. The provision of optional files, including photorealistic 3D models, and unfolded views of panoramic (RGB/intensity/thermal IR) images is recommended. If the survey task aims to detect abnormal features found in manholes, then these features shall be identified on the point cloud.

(b) In the drawing, the location(s) of feature(s), if any, shall be connected to the identified utility alignment, ground features like valves, roads and buildings contained in the location plan. All reported coordinates and levels should be represented in HK 1980 Grid coordinates based on HK80 Datum (The coordinates for N,E are presented as 8*****.***, 8*****.***, relative to the HK80 Datum. Normally, "All levels are referred to HKPD" and must be present in the survey plan).

(c) For submission of other materials in CAD and GIS format, requirements in Computer-Aided-Drafting Standard for Works Projects (CSWP) Version 1.03.00 (2007) and Geographic Information System (GIS) Specifications for Engineering Surveys of Highway Department (2015) shall be followed, respectively.

G – Limitations

When the survey cannot be completed or completed with limitations, the reasons of limitations shall be declared according to the examples given below in Table 5. The lab/survey company shall expand the list as an in-house procedure, if necessary.

Table 5 Limitations of laser scanning survey

Type of survey	Limitations	Examples
Laser scanning survey	Stability	High wind speed in the manhole may cause instability when the laser scanner is lowered down by a rope or a winch.
	Near-distance effect	Objects that are too close to the laser scanner may cause null return (e.g. manhole shaft).
	Null returns / data voids	Null return may also be found on clean and calm water bodies, or moist surface in/on the underground pipes or manholes, if NIR laser is used (due to laser energy absorption).
	Insufficient illumination	External or on-board camera is unable to capture colorized point cloud if the underground environment is dark or hazy.
Others	Record drawings	Utility information is not available or incomplete or is in general inaccurate.
	UTR (unable to raise)	Underneath a car, keyhole damaged or no keyhole found, pit/manhole cover tightly closed, oil in pit/manhole, pit/manhole on carriageway and no temporary traffic arrangement (TTA), work in progress, pit/manhole cover corroded, obstructed, harmful pest (e.g. bees).
	UTL (unable to locate)	The pit/manhole is shown in record plan but could not be found on site.
	UTGA (unable to get access)	Private area, pump room, construction site inside the survey area, access points are far away from the survey area but the alignment is believed to enter the survey area, thus the alignment may be missed.
	UTS (unable to survey)	Full of silt/water, abandoned pit/manhole.
	SA (survey abandoned)	Pipe obstruction, pipe blocked/collapsed, high water flow rate within the pit/manhole, vermin.

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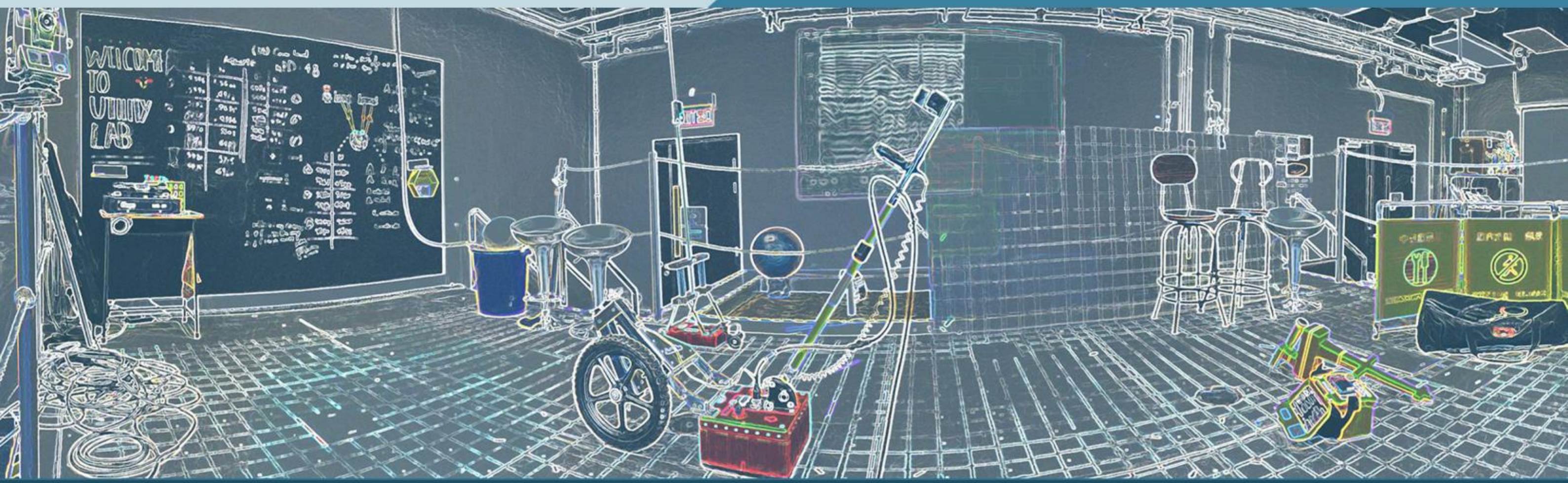

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