เทคนิคชั้นสูงของการสอบเทียบเครื่องวัดระยะชนิดเลเซอร์
An advanced technique of laser distance meter calibration

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บทคัดย่อ

ปัจจุบันเครื่องวัดระยะชนิดเลเซอร์ส่วนมากนิยมใช้วัดระยะในงานก่อสร้าง และงานที่เกี่ยวข้องกับการประยุกต์ใช้การวัดทั่วไป ในขณะที่ห้องปฏิบัติการสอบเทียบความยาวต้องการหาวิธีการสอบเทียบและการสอบกลับได้ของเครื่องมือวัดนี้ งานวิจัยนี้นำเสนอเทคนิคชั้นสูงด้วยหัววัดแบบอัจฉริยะ ในการตรวจสอบความถูกต้องเครื่องวัดระยะด้วยเลเซอร์ โดยอ้างอิงบนพื้นฐานหลักการของมาตรฐาน ISO 16331-1 (2012) ที่ระยะอ้างอิงสูงสุด 20 m ด้วยค่าความสามารถการวัดลดลงที่ค่า 0.64 mm, 0.73 mm, และ 0.80 mm ของ 3 ตัวอย่าง ที่ระดับความเชื่อมั่นโดยประมาณ ร้อยละ 95

Abstract

Recently, the laser distance meter mostly employed in construction area, and other related to measurement applications. Whereas, the length calibration laboratory certainly needs to find out both technical calibration and their traceability. This research presents the advanced technique of smart measuring probe for performance test method of laser distance meter, based on ISO 16331-1 (2012). The minimized measurement uncertainties are 0.64 mm, 0.73 mm, and 0.80 mm of 3 samples, at maximum range of reference distance 20 m, the confident level at approximately 95%.

คำสำคัญ : เครื่องวัดระยะชนิดเลเซอร์ หัวโพรบอัจฉริยะ สอบเทียบ ค่าความไม่แน่นอนการวัด

Keywords : Laser distance meter, Smart measuring probe, Calibration, Measurement uncertainty

1. Introduction

The laser distance meter (LDM) also known as an electronic distance meter (EDM), or rangefinder, or laser telemeter is employs time of flight principle [1] , which a laser (solid states) beam to determine the distance to an object, it was developed by Leica, in 1993. There are many of measuring applications, such as building, interior decoration, room dimensions, conveyor belt lengths, bridge construction highway survey, and so on. Although, in the present the LDM is more comfortable, and precise than the long range measuring instruments, it needs to calibrate and metrological traceability as well.

Generally, the LDM is simply used the manual calibration by comparison method with interferometry, high precision EDM, and standard tape which is set up on. These activity would be usually provided by the national metrology institute (NMI), at the range up to below 50 m, as EURAMET Supplementary Comparison (L-S20) [2].

Hence, the standard tape calibration bench 50 m in the length and dimensions calibration laboratory, Department of Science Service (DSS) is developed in 2009 [3]. In order to provide the traceability of long range electronic distance device, in Thailand. LDM calibration by using interferometry technique of

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DSS have been developing since 2017, which is typically based on ISO 16331-1/2012 (part 1) Performance of handheld laser distance meters [4]. But the measurement uncertainty of LDM calibration is practically up to 1.0 mm or more larger, that caused by some technical problems of human error. The repeatability and measurement uncertainty (MU) are manually also very large from manual effect of setting up.

This research presents an advanced design of automatic smart probing technique using the interferometry system, in order to minimize repeatability and measurement uncertainty. The comparison results of LDM calibration is satisfy |between the manual method and new automated technique method. The measurement uncertainty and repeatability decrease significantly.

The next research would challenges to investigate how to reduce the residual errors with completely the measurement uncertainty evaluation technique of LDM calibration at the confident level 95%. To evaluate the sources of uncertainty and contributes uncertainty budgets.

2. Principles

2.1 Time of flight (TOF)

The LDM principle is based on the time of flight (TOF). In Fig.1, shown the diagram of LDM principle, the distance (D) is the light path propagates from light source to target or object and return back to receiver with light velocity (c) and time (t) divides by 2, as equation (1).

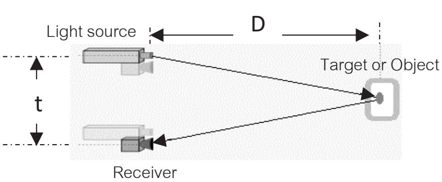


Figure 1 : *The time of flight principle of LDM*

$$D = \frac{ct}{2} \quad (1)$$

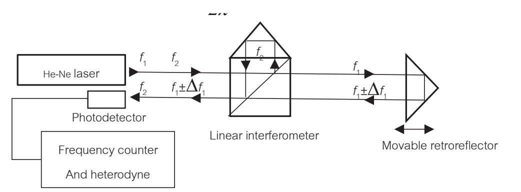
When, D: Distance, c: Light velocity, t: Time to travel a distance through a medium

2.2 Interferometry method

The interferometry method is the absolute method as shown in Fig.2 the light source is a He-Ne laser with wavelength 633 nm, power output less than 1 mw based on light interference principle refer to Michelson's interferometer principle. To develop heterodyne interferometer two frequencies f_1 and f_2, as equation (2) [5].

$$\Delta f = \frac{\Delta \phi}{2\pi} \lambda_a \quad (2)$$

The principle of linear interferometry as shown in Fig.2 has directly view linear interferometer, and movable retroreflector. The result of interference is 2 images f_2 (f reference) and Δf of the interference fringe which interference pattern is observed by photodetector, and interpreted fringe to distance with frequency counter, and heterodyne.



$$f_{reference} = f_2 \;,\; \Delta f = f_1 \pm \Delta f_1$$

Figure 2 : *Principle of interferometry method*

2.3 Design of smart measuring probe

A smart measuring probe (SMP) carriage is only special designed for LDM calibration system. The carriage chassis made of a high quality material (Aluminium No.7075). The measurement positioning is controlled by the high precision motorized DC driving wireless control of each measuring points with repeatability approximately ±0.002 mm. The

SMP automatically moves along the straightness of guideway, both pitch and yaw less than ±300 arcsec., for all reference distance 20 m. The LDM and laser interferometer beams are accurately provided parallelism movement both the LDM target and linear retroreflector, as show in Fig.3.

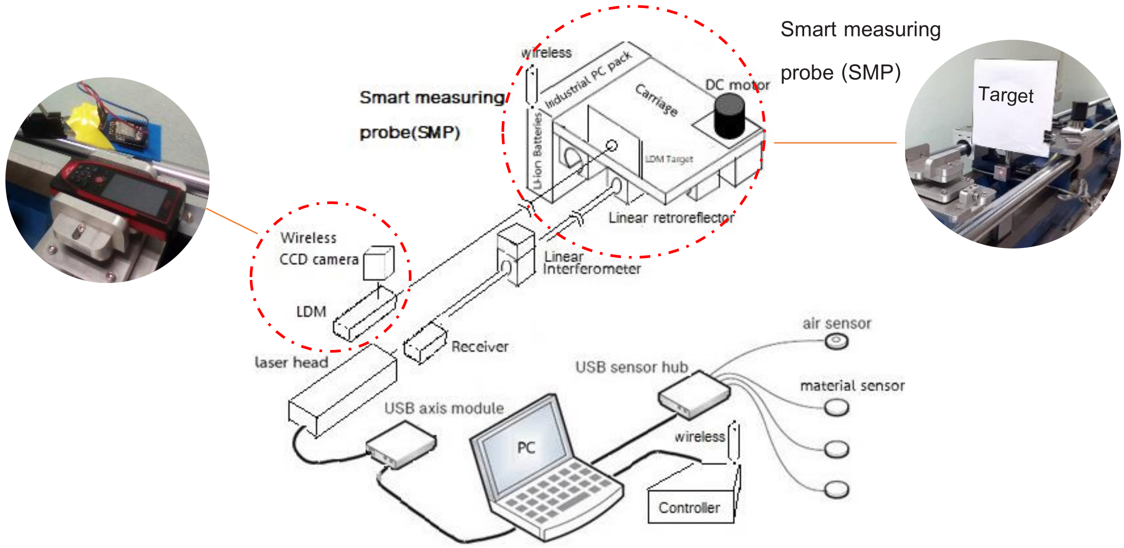


Figure 3 : The design of smart measuring probe (SMP)

The algorithm of SMP, the measurement positioning of smart probe is defined by the operator setting on the PC and computerized software XAMPP control panel Version 3.2.2 [6]. Whatever, the measuring probe approaches to any measuring points, the smart probe would decelerate slowly stop the carriage when comes over each measuring point, and then move to next measuring point. Each of |measuring points automatically is observed and collected the data from laser interferometer by CCD camera via the software, until the program runs completely all measuring points, as Fig. 4 the flow chart of the running program.

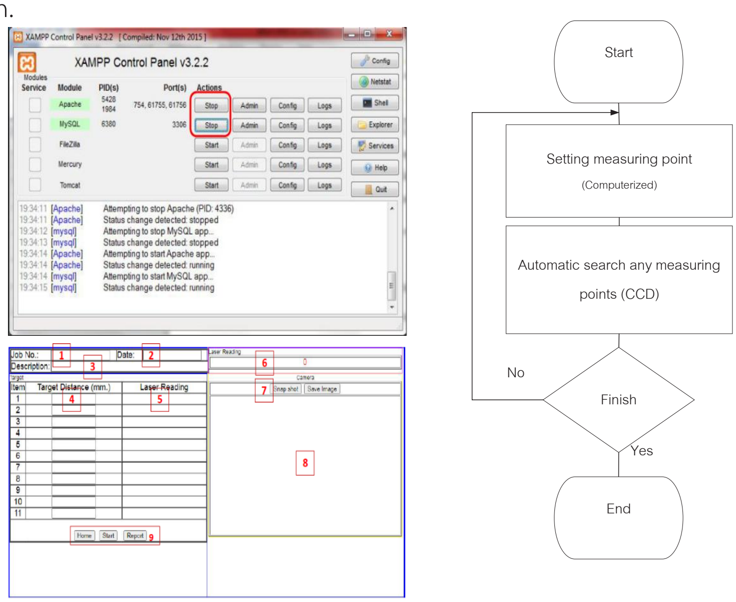


Figure 4 : The program XAMPP and flow chart of the measuring program

3. Experiments

The measuring tape calibration bench 50 m applied for the LDM calibration system consists of the long bench of standard tape calibration system 20 m, laser interferometer (He-Ne, wavelength 633 nm) and optical devices (linear interferometer and retroreflector), 6 material and 6 air temperature sensors, all devices set up on measuring bench together with optical devices, such as linear interferometer, retroreflector and mounted CCD camera over LDM, as following Fig.5.

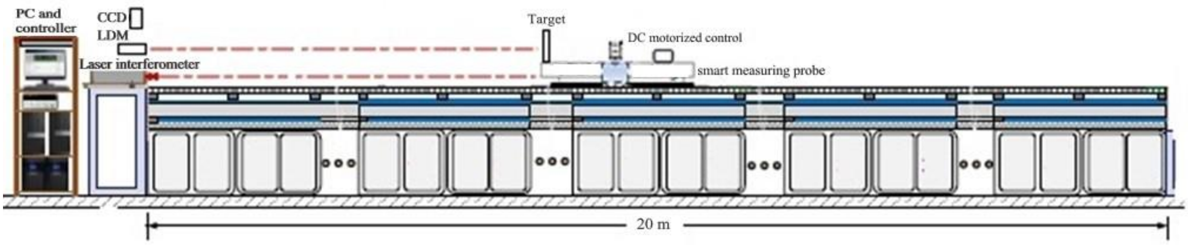


Figure 5 : *Laser distance meter measuring bench 20 m*

The calibration points (CP) up to 10CP would be defined either to the longest specified distance of the device under test or to the maximum range of the reference distance measurement system. In this case, laboratory set up only the maximum range of the reference distance at 20 m, as show in Fig.6. At each calibration point would take 3 measuring runs, until complete 10 calibration points (each point 10 repeats) with the reference distance measurement system, with the unit under calibration, in order to make sure that the configuration alignment of LDM to target is correct.

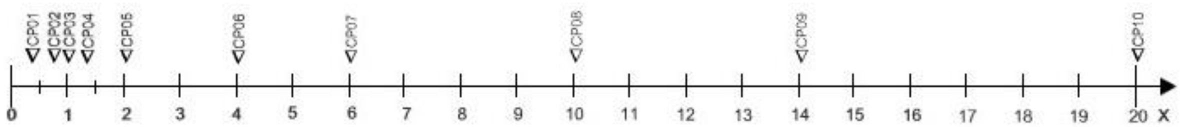


Figure 6 : *The calibration points or check points*

The 10 calibration points set as following ISO 16331-1/2012 (part 1)

1. D(CP01) = 0.02*D(CP10) = 0.4 m (400 mm)
2. D(CP02) = 0.03*D(CP10) = 0.6 m (600 mm)
3. D(CP03) = 0.05*D(CP10) = 1.0 m (1000 mm)
4. D(CP04) = 0.07*D(CP10) = 1.4 m (1400 mm)
5. D(CP05) = 0.10*D(CP10) = 2.0 m (2000 mm)
6. D(CP06) = 0.20*D(CP10) = 4.0 m (4000 mm)
7. D(CP07) = 0.30*D(CP10) = 6.0 m (6000 mm)
8. D(CP08) = 0.50*D(CP10) = 10.0 m (10000 mm)
9. D(CP09) = 0.70*D(CP10) = 14.0 m (14000 mm)
10. D(CP10) = max. distance = 20 m (20000 mm)

Where X : Distance (m), maximum range of the reference distance : 20 m

Note : *The calibration or check point of classical method is 0, 500, 1000, 2000, 3000, 4000, 5000, 10000, 15000, 20000 mm.*

The measurement conditions set up under laboratory conditions with temperature 25°C ± 3°C or , relative humidity 50% ± 10 % target reflectivity 95% ± 5% and background illumination < 3000 lx (indoor conditions).

Reference standards:

1. Measuring bench 0-20 m with smart measuring probe
2. Laser measurement system 5529A (optional for long range application up to 80 m)

Unit under calibrations:

1. UUC-1: Fluke 411D, Range 0-30 m, (DSS's artifact)
2. UUC-2: Leica DISTO D8, Range 0-250 m (customer), and
3. UUC-3 Leica DISTO A5, Range 0-20 m (customer)

4. Results and Discussion

4.1 The corrections and repeatability

As mentioned above, the calibration points based on ISO 16331-1(2012) 10CP (Fig.6) have been starting since 2017. The correction comparison of UUC-1 (Y2017 & Y2019), UUC-2 (Y2016 & Y2019, and UUC-3 (Y2016 & Y2018) as Figure 7, Figure 8, and Figure 9 respectively, are compared between the manual and SMP method. Therefore the UUC-2 and UUC-3 would be compared correspondently only the nominal value of 0, 2000, 4000, 10000, 20000 mm.

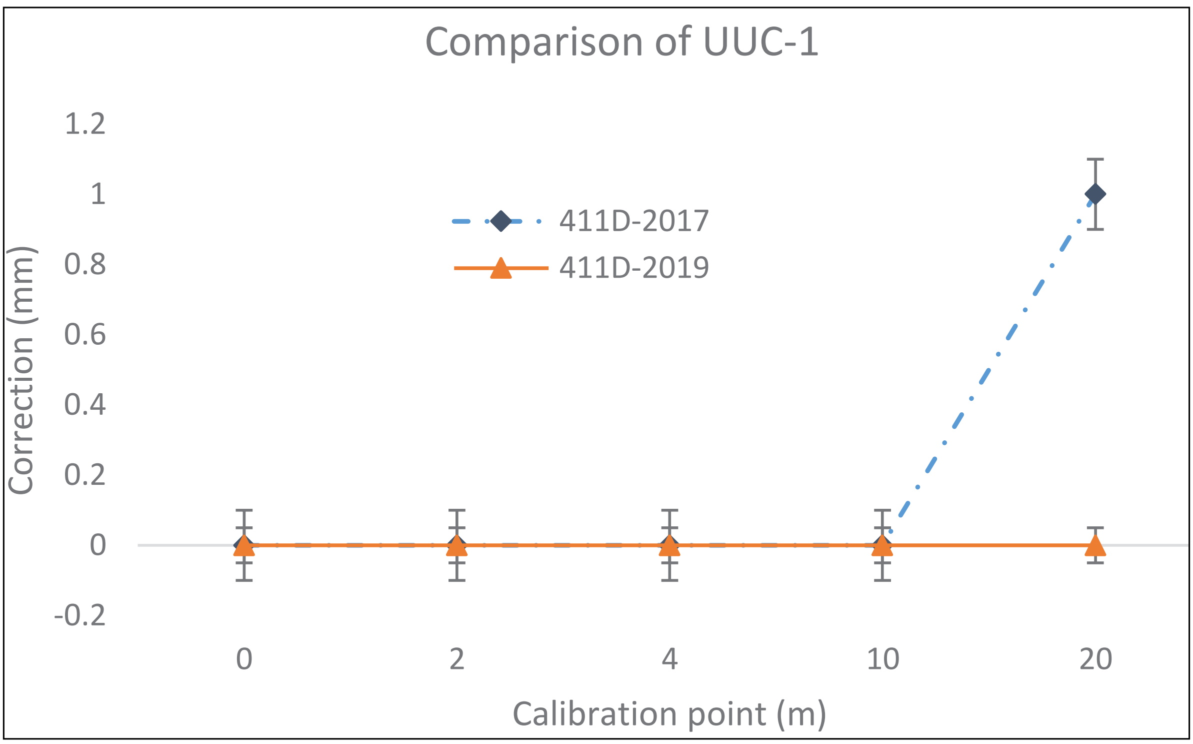


Figure 7 : The comparison of UUC-1(Y2017-Y2019)

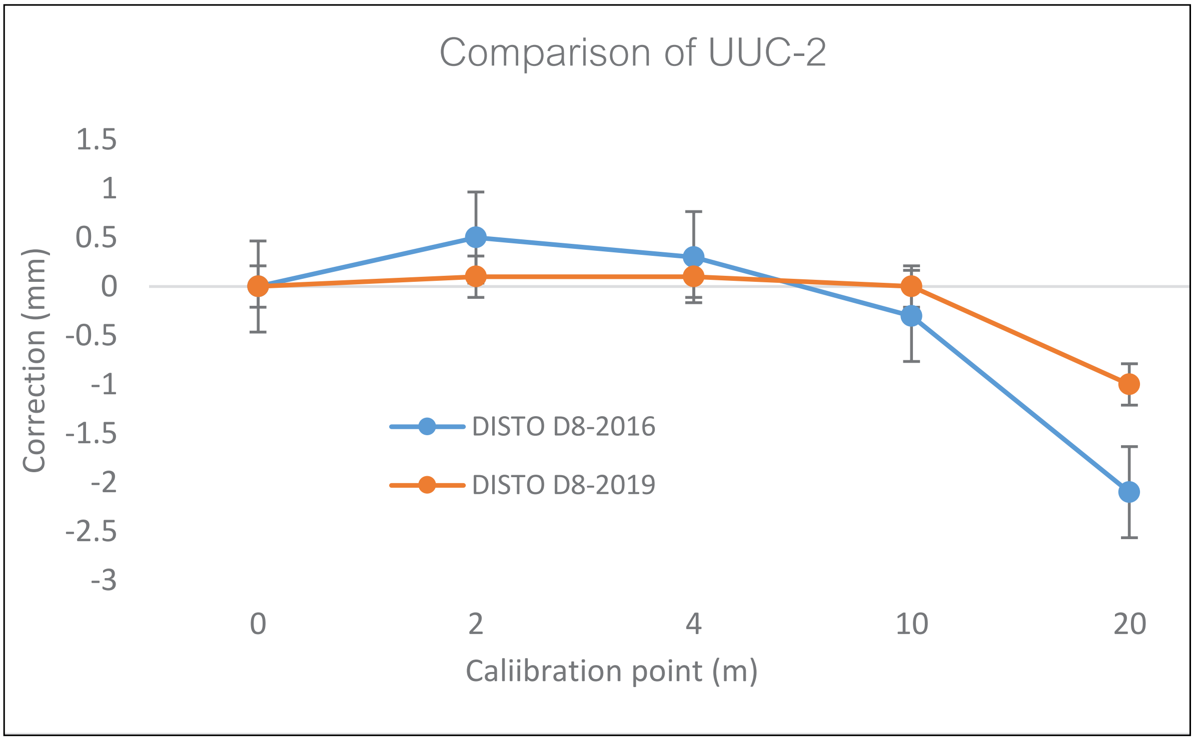


Figure 8 : The comparison of UUC-2 (Y2016-Y2019)

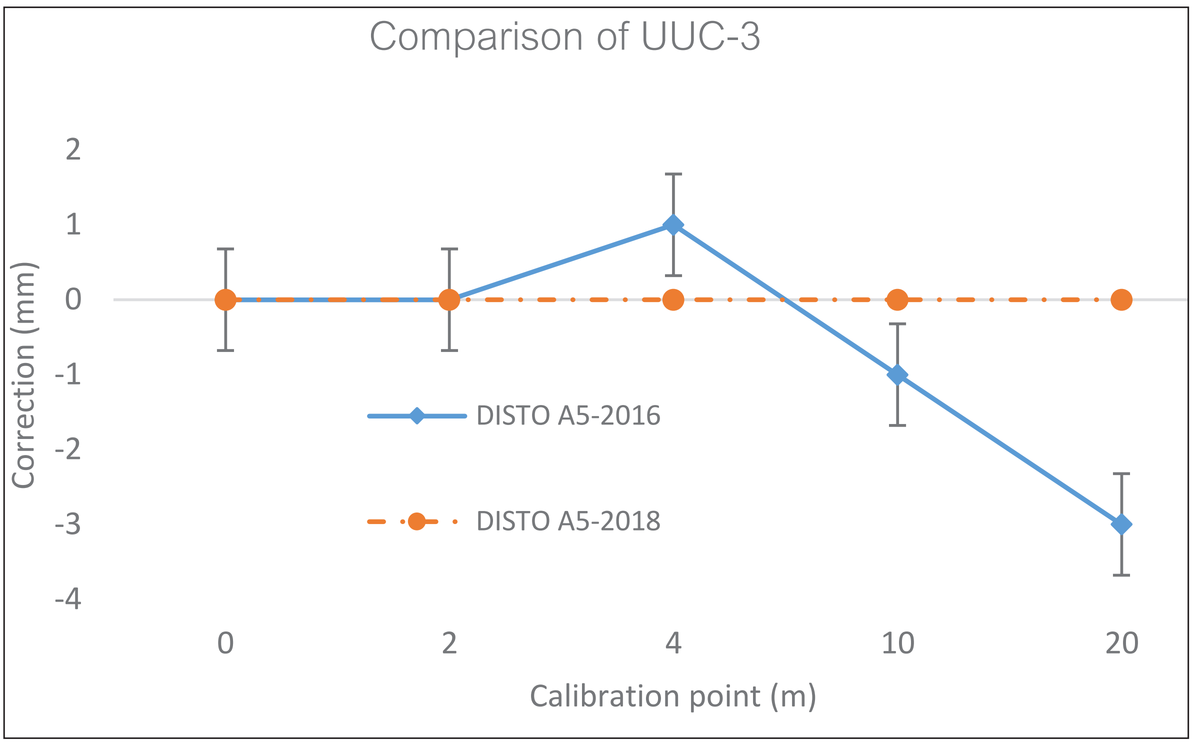


Figure 9 : The comparison of UUC-3 (Y2016-Y2018)

The repeatability of UUC is compared with each other, at the same calibration point and difference methods between manual and automatic system of SMP, as showed in Table1.

Table 1. Repeatability Comparison of UUC1, UUC2,
and UUC3 between Manual and SMP

Nominal value (mm)	UUC1		UUC2		UUC3	
	Manual (2017)	SMP (2019)	Manual (2016)	SMP (2019)	Manual (2016)	SMP (2018)
0	0.33	0	0.05	0.14	0	0
2000	0.33	0	0.05	0.14	0	0
4000	0.33	0	0.05	0.14	0	0
10000	0	0	0.04	0.09	0.2	0
20000	0.33	0	0.03	0.12	0	0

However, the repeatability of SMP method is obviously more stable than the manual method. The authors expect that their long-term stability of SMP is certainly better than classical method as well.

4.2 Measurement uncertainties

This measurement uncertainty evaluation based on M3003 (2012), the guideline to the expression of uncertainty in measurement [7]. Hence, the 12 source of uncertainty budgets and flow chat of measurement uncertainty budgets, as following, Figure 10 below.

1. Standard accuracy, (u_s)
2. Dead path error of standard, (u_D)
3. Resolution of standard, (u_{rs})
4. Resolution of UUC (u_{ru})
5. Abbe error of measuring bench (u_{mb})
6. Abbe error of standard, (u_{ms})
7. Cosine error of standard, (u_{cs})
8. Cosine error of UUC, (u_{cu})
9. Drift of standard, (u_d)
10. Refractive index of air, (u_{in})
11. Zero positioning error of standard, (u_z)
12. Temperature effect, (u_t)
13. Deviation (u_{Dev})

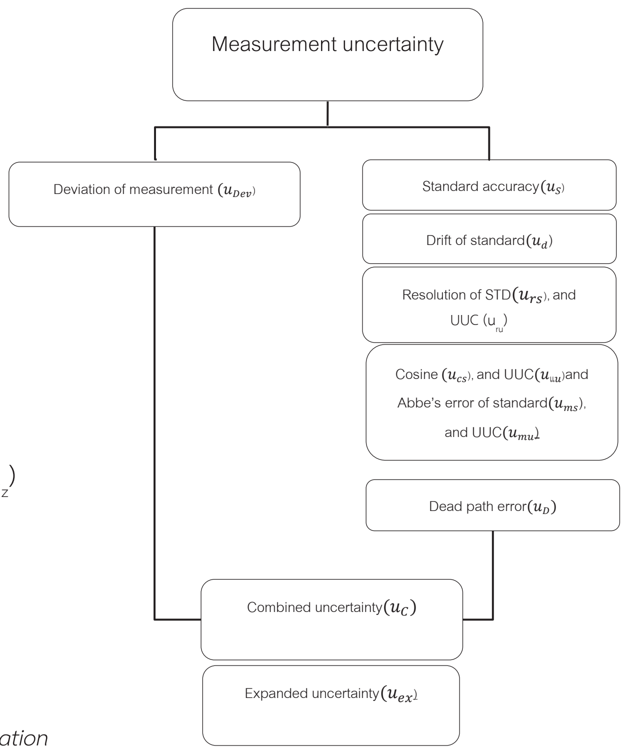


Figure 10 : *Sources and flowchart of uncertainty evaluation*

$$U_y^2 = u_D^2 + u_s^2 + u_d^2 + u_{(rs,ru)}^2 + u_{(ms,mu)}^2 + u_{(cs,cu)}^2 + u_t^2 + u_{zs,zu}^2 + u_{in}^2 \tag{3}$$

Each source of measurement uncertainty budgets were declared and combined of root sum square, as equation (3). u_D^2, u_s^2, u_d^2, $u_{rs,ru}^2$, $u_{ms,mu}^2$, $u_{cs,cu}^2$, u_t^2, $u_{zs,zu}^2$, and u_{in}^2 .In case of air index effect, which is not change from the previous value, caused by limitation of setup equipment. The comparison results of measurement uncertainty, as shown in Table 2.

Table 2. Comparison of measurement uncertainty of UUC1, UUC2, and UUC3

Nominal value (mm)	UUC1 (mm)		UUC2 (mm)		UUC3 (mm)	
	2017	**2019**	**2016**	**2019**	**2016**	**2018**
0	1.1	0.17	0.68	0.33	2.0	0.60
2000	1.1	0.17	0.68	0.33	2.0	0.60
4000	1.1	0.17	0.68	0.33	2.0	0.60
10000	0.9	0.33	0.71	0.39	2.0	0.64
20000	1.3	0.64	0.84	0.73	2.0	0.80

5. Conclusions

The comparison results of measurement uncertainty for UUC1 (411D), UUC2 (DISTO D8), and UUC3 (DISTO A5) at the distance 20000 mm, reducing measurement uncertainty as 0.66 mm, 0.11 mm, and 1.2 mm, or up to 50.7%, 10.7%, and 60% respectively at the confidence level 95%, which is decreasing significantly within maximum permissible error ±1.0 mm, due to reducing of repeatability. Recently, length calibration laboratory of DSS accredited ISO 17025 (2017), scopes of LDM measuring range with calibration and measurement capability (CMC), issued update on 2020, as Table 3.

Table 3. The calibration and measurement capability of LDM

ช่วงการวัด	ขีดความสามารถการสอบเทียบและการวัด (CMC)
0 up to 6 m	±0.26 mm
> 6 up to 10 m	±0.38 mm
> 10 up to 16m	±0.54 mm
> 15 up to 20 m	±0.65 mm

The next research would present how to investigate the main factor of error, and to evaluate or discuss more details the sources of uncertainty and contributes uncertainty budgets technique of LDM calibration at the confident level 95%.

6. Acknowledgement

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7. References

[1] *Time of flight* [online]. [viewed 17 February 2021]. Available from: https://en.wikipedia.org/wiki/Time_of_flight

[2] WISNIEWSKI, M. and Z. RAMOTOWSKI. EURAMET Supplementary Comparison, EURAMET.L-S20 (#1169). *Comparison of laser distance measuring Instruments*. Final Report. [online]. [viewed 20 February 2021]. Available from: https://www.bipm.org/utils/common/pdf/final_reports/L/S20/EURAMET.L-S20.pdf

[3] CHINCHUSAK, W. and V. TIPSUWANPORN. Investigation of yaw errors in measuring tape calibration system. *Measurement*. 2018, **125**, 142-150.

[4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *ISO 16331-1:2012. Optics and optical instruments — Laboratory procedures for testing surveying and construction instruments — Part 1: Performance of handheld laser distance meters*. 2012.

[5] AGILENT TECHNOLOHIES, INC. 2010, Laser Measurement System 5529A - User's Guide. Hewlett-Packard Company, 5301 Stevens Creek Boulevard, Santa Clara, California 95052-8059. May 10, 2010.

[6] Program XAMPP version3.2.2, work instruction for Laser Meter Certification Project – LMCP, First Edition, 2020-10-13.

[7] UNITED KINGDOM ACCREDITATION SERVICE. M3003. *The expression of uncertainty and confidence in measurement*. EDITION 3, NOVEMBER 2012.