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## Laser Distance Sensors Evaluation for Geomatics Researches

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### Abstract

In this study, an approach inspired by a standardized calibration method was used to test a laser distance meter (LDM). A laser distance sensor (LDS) was tested with respect to an LDM and then a statistical indicator explained that the former functions in a similar manner as the latter. Also, regression terms were used to estimate the additive error and scale the correction of the sensors. The specified distance was divided into several parts with percent of longest one and observed using two sensors, left and right. These sensors were evaluated by using the regression between the measured and the reference values. The results were computed using MINITAB 17 package software and excel office package. The accuracy of the results in this work was  $\pm 4.4\text{mm} + 50.89 \text{ ppm}$  and  $\pm 4.96\text{mm} + 99.88 \text{ ppm}$  for LDS1 and LDS2, respectively, depending on the LDM accuracy which was computed to the full range (100 m). Using these sensors can be very effective for industrial, 3D modeling purposes, and many other applications, especially that it is inexpensive and available in many versions.

**Keywords:** Sensors; Laser Distance Sensor; Laser Distance Meter; Geomatic applications; Additive Constant.

### تقييم متحسسات المسافة الليزرية لبحوث الجيوماتك

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### الخلاصة

في هذه الدراسة استُخدمت طريقة معايرة مستوحاة من طريقة قياسية مستخدمة لفحص مقياس المسافة الليزري (LDM) لفحص متحسس قياس المسافة (LDS)، باستخدام مؤشرات إحصائية ومؤشرات قوة العلاقة تم حساب الخطأ الإضافي وتصحيح المقياس. تقسم مسافة الفحص الى عدة أجزاء نسبةً الى المسافة الأكبر، تم قياس المسافات باستخدام اثنان من المتحسسات، يمين ويسار، وتم تقييم المتحسسات باستخدام قوة العلاقة بين القيم المقاسة والقيم المرجعية لمقياس المسافة الليزري. النتائج تم حسابها باستخدام برنامج (MINITAB 17) وبرنامج (Excel). دقة المتحسس الاول (LDS1) كانت  $\pm (4.4\text{mm} + 50.89 \text{ ppm})$  ودقة المتحسس الثاني (LDS2)  $\pm (4.96\text{mm} + 99.88 \text{ ppm})$  متر وتبين ان (LDS) يعمل بدقة قريبة بدرجة كبيرة من دقة (LDM). استخدام هذه المتحسسات فعال جداً في التطبيقات الصناعية ولأغراض النمذجة ثلاثية الابعاد والكثير من التطبيقات لاسيما وانها متوفرة بأنواع كثيرة وبأسعار مناسبة.

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## 1. Introduction

Development and growth of geomatics research is based on the tools (hardware) and devices and their availability mainly for researchers. This is in sometimes more important than programs (software) and theoretical manners which are obtainable, especially for unfunded research. On the contrary of that, when suitable equipment is available, the opportunity of producing high quality and useful research in many geomatic applications is great. Escalation of the tools used for researchers opens the area for a heavy research production. One of the tools in geomatics engineering is the sensors available in electronics stores. The sensors related to direction determinations were used in geomatics researches and found their way to geomatics applications. This work attempts to introduce the commercial Laser Distance Sensor (LDS) as a useful tool in geomatic applications by the statements of costs. Indoor field test according to a standardized method, statistical explanation accuracy, precision, and suggesting applications, can be used for this type of sensors. In this article, we are interested LDSs, but the lack of reliability of this product is an obstacle to the tendency of specialists in the branches of geomatics and surveying engineering to use them extensively in researches, especially those sensors that provide precisely the fundamental element of geomatic research, which is the distance measurement.

The motives for qualitative control of such tools are always present, such as improving accuracy reliability, calculating work error, and even legal matters related to surveying engineering works. Recalibrations on annual basis or depending on the age of the sensor can be sufficient and safe [1, 2].

An earlier work [3] combined the photogrammetry with the distance measurement and provided an ability to build an objects surface such as the façade buildings or any feature. Using any version of LDM may satisfy this purpose, but may not satisfy large surface measurements. Other reports [4, 5] combined the laser distance meter with a close range photogrammetry to develop 3D measurements of buildings under construction. They used the LDM with photogrammetry, which represents a combined technique to improve the accuracy and reduce the cost. The LDS is better than the LDM in size, weight, flexibility, cost, synchronization and installation in photogrammetric systems, which supports the opportunity for more applications. A previous study [6] used the inertial sensors, such as those in smartphones, by gaining the geographical location data, and tested the accuracy and precision obtained with these sensors.

Distance measurement component was used in many researches; one study [7] explained that the monocular vision attitudes are favorable when compared with the stereo vision systems, because of the simplicity and concisely in size, weight and power, especially in robotic or semi-robotic works. Also, the monocular vision systems, when combined with distance measurement options, provided a correctable scale.

An earlier work [8] showed how to build a 3D model for a heritage building using a photogrammetry combined with laser distances measurements by total station to make a ground referenced points. Another work [9] outlined a method with software to check the performance of low-cost sensors (accelerometer and magnetometer) for geomatics applications.

International Organization for Standardization ISO organization mainly describes the factors affecting laser distance measurements through the handheld laser distance meter test description. These factors were detailed elsewhere [10, 11] as described below.

### 1) Target Reflectivity

Signal to noise ratio (S/N) is higher for targets which have high reflectivity, that gives better measurement performance. The typical targets for laser distance measurements are the painted targets such as bricks, concrete, steel parts, doors, windows and other targets.

### 2) Background illumination

The weak performance of laser instruments is related to surrounding environment of measurements. The background illumination is affecting directly the performance of laser instruments. In outdoor applications, the natural light (the sun light) value reaches to thousands of lux unit (lx), that causes a retrogression of the signal / noise ratio and therefore the performance of the instrument will be weak. For indoor applications, the background illumination can be of a neglectable effect.

### 3) Temperature

Temperature is among other key components with atmospheric influences (e.g. air pressure and humidity).

#### 4) Display Resolution

The instrument used to display the measurements should be of two times better than the measurements tool accuracy, so that it is related to the code reader program.

##### 1.1 Errors

Usually, the errors of electro-optical distance measurement tools are inseparable to the design, industrialization and allowance of the component, not care of the pulse and phase measurements basic. Table-1 summarizes in general the main errors that raise user concerns in industry. The phase and amplitudes of the short periodic errors change with distance, signal strength, time and ambient light [1]. We note that increasing the signal strength will decrease the ambient light effects, with certain limits.

**Table 1**-Summery of Manufacturing Errors of Electro-optical Distance measurement tools

Instrument Correction (I.C.)	Terminology	Caused By	Manufacturer Action	User Action
Additive Constant	-Zero error -Instrument error	-Instrument vertical axis -Industrial parameters -Ambient reasons	Built in Correction	Consequence of re-determining the remaining correction computations
Short Periodic Errors	-Cyclic errors -First order short periodic errors	-Electrical or/and optical crosstalk -Systematic error in phase measuring system -Multipath -Time interpolation procedure	-Anti reflex coating -Electrical shielding of transmitter and receiver	Calibrate for this error and correct the measurements
Scale Errors	—	-Oscillator -Emitting and receiving diodes -External factors	-Check the industrial parts -Check the product	Depends on manufacturer check, the remaining is computed by evaluation.

## 2. Measurement System

The measurement system consists of a composite frame supported on a tripod. On this frame, the LDS was fixed in two pieces, right and left. The laptop was also placed on the frame. The reference distance was measured by LDM and fixed manually at the exact position when the measurement started. Table-2 presents the specifications of the LDM, where the operating conditions are mainly typical and unfavorable.

The LDS is about mini to normal product size (17\*41, 25\*45, 40\*72 mm). The price of these sensors is certainly lower than that of the instruments which can be used instead. Figure-1 and Table-3 show the technical specifications of the available commercial LDS.

For LDS, the software of a commercial sensor (Geshe Beacon) was used. It is a simple software that comes with the sensors and used to start measurement and for the settings of the sensor, power, port and other related settings. The LDM is fixed exactly at the touch front of the LDS and carefully oriented to the same point on the target. The measurements were targeted to a painted grey wall in the laboratories of University of Kufa, Faculty of Engineering.

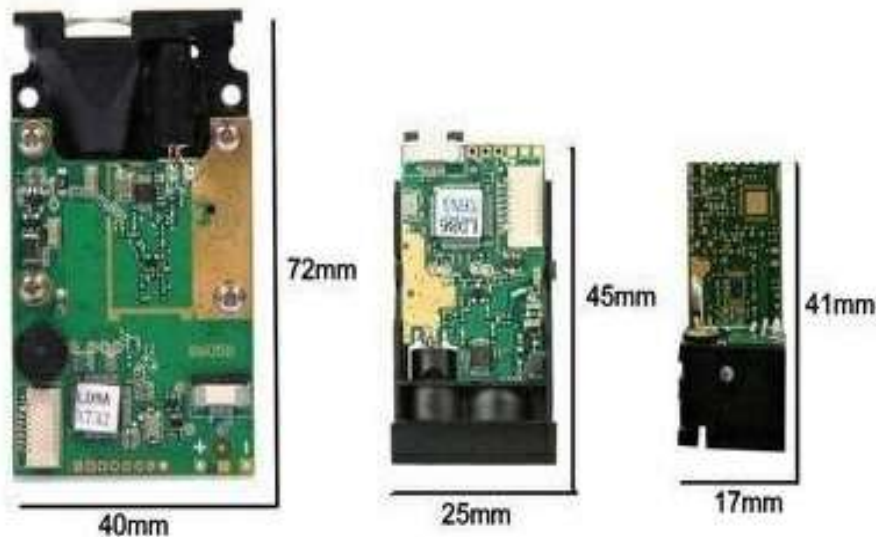
**Table 2**-Related Specifications of Reference Distance Meter [12]

Technical Data	
Digital Laser Measure	GLM 100
Measuring range (max.)	100 m <sup>A</sup>
Measuring range (typical)	0.05-80 <sup>B</sup>

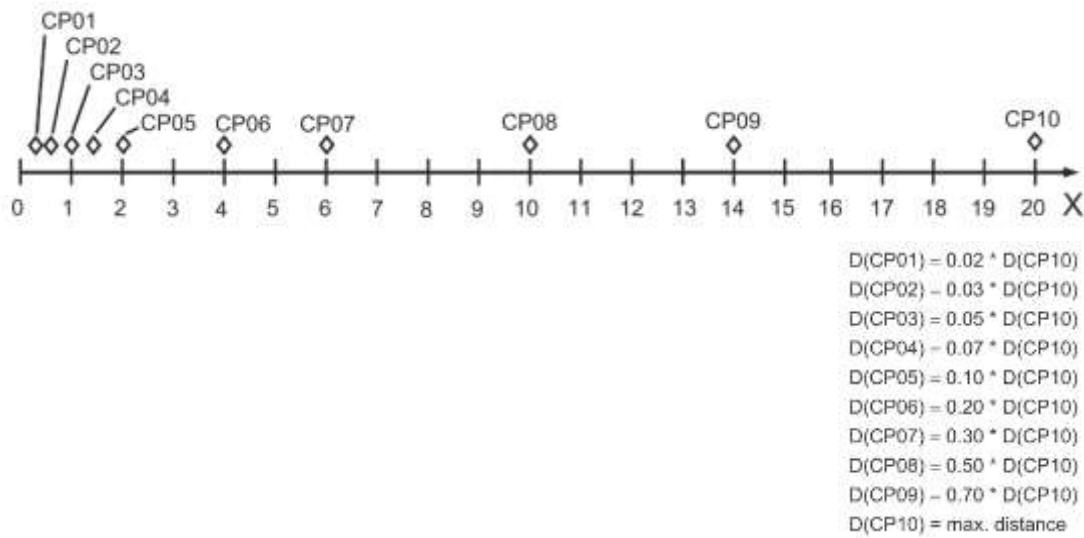
Measuring range (typical under unfavorable conditions)	45 m <sup>C</sup>
Measuring accuracy (typical)	±1.5 mm <sup>B</sup>
Measuring accuracy (typical under unfavorable conditions)	±2.5 mm <sup>C</sup>
Operating temperature	-10 <sup>0</sup> C...+50 <sup>0</sup> C
Relative air humidity, max.	90%
Laser class	2
Laser type	635nm, <mW
<p>A) For measurements from the rear measuring-tool edge, the operating range increases the better the laser light is reflected from the surface of the dispersive target, not reflective and the brighter the laser point is with respect to the ambient brightness indoors and twilight. For distances greater than 80 m, we recommend using a retroreflective target plate as an accessory. For distances below 20 m, a retroreflective target plate should not be used, as it can lead to measuring errors.</p>	
<p>B) For measurements from the rear measuring-tool edge, 100% reflectance of the target (e.g., a white-painted wall), weak backlight and 25<sup>0</sup>C operating temperature. Additionally, a deviation influence of ±0.05 mm/m must be taken into account.</p>	
<p>C) For measurements from the rear measuring-tool edge, 10.- 100% reflectance of the target, strong backlight and .-10<sup>0</sup>C to +50<sup>0</sup>C operating temperature. Additionally, a deviation influence of ±0.29 mm/m must be taken into account.</p>	

**Table 3**-Technical Specifications of the available commercial LDS

Accuracy	±1 mm (0.04 inch)
Measuring Unit	meter/inch/feet
Measuring Range (without Reflection)	0.03-100m/0.03-120m/0.03-150m
Measuring Time	0.1~3 seconds
Laser Class	Class II, Class II M and Class III A



**Figure 1**-The Sizes of LDSs Until the Current Time.



**Figure 2-**Laboratory Experiment to Measure Distance as Inspired by [10].

**3. The Method**

The method used to examine the sensors is inspired by the laboratory procedures for testing surveying and construction instruments described previously [10]. It shows how to test the handheld LDM with respect to the reference distance measurement system, but here the LDM was used as a reference tool because it is usually verified by the producer and has a specified accuracy. The specified distance was divided to several parts with percent of longest one by 0.02, 0.03, 0.05, 0.07, 0.10, 0.20, 0.30, 0.40, 0.50 and 0.70. Figure-2 explains that. The total distance is selected according to the available distance in the lab and the suitable target. The measurement starts from the longest distance toward the shortest one, with every measurement by the sensor being followed directly by a measurement using the LDM. The distances were observed using two sensors, left and right (LDSs, but this does not imply that the distances were the same for both sensors, because the frame was difficultly set up parallel to the wall target. Then, the comparisons between every side sensor with the corresponding reference distance meter were independently performed.

**4. LDS Accuracy**

The equations of the propagation of error and the major error of components of the observed distance were explained earlier [13]. We can use an equation inspired by those equations to compute the accuracy (typical under unfavorable conditions) for the LDM at a nominal range (eq.1).

$$E_d = \sqrt{E_i^2 + (ppm * D)^2} \dots (1)$$

where  $E_d$ : the measurement accuracy,  
 $E_i$ : instrument accuracy according to the conditions  
 $D$ : the measured distance.  
 $ppm$ : part per million.

To compare the LDS measurements with those of LDM as reference measurements, we can use the suitable statistical indicators. We calculate the deviation ( $\Delta Mi$ ) in equation (2), the experimental mean value of the distance measured ( $\overline{D}$ ) in equation (3), the deviation ( $\Delta \overline{D}$ ) of the experimental mean value from the corresponding reference value in equation (4), and the corresponding standard deviation ( $s$ ) of the measured values and the standard uncertainty ( $u$ ) of the measured values in equation (5) [14].

$$\Delta m_i = m_i - D_{ref} \dots (2)$$

$$\bar{D} = \frac{1}{N} \sum m_i \quad \dots \dots (3)$$

$$\Delta \bar{D} = \bar{D} - D_{ref} \quad \dots \dots (4)$$

$$u = s = \sqrt{\frac{1}{N-1} \sum (m_i - \bar{D})^2} \quad \dots \dots (5)$$

The regression between the laser sensor and the reference laser distance meter can be represented as a linear regression. After (J.M. Rueger), the following set of equations were used to explain the geometrical regression of LDS and LDM. The determination of the additive constant for LDS measurements and the scale correction with respect to LDM were performed by solving this linear regression.

$$\hat{y} = a + bx \quad \dots \dots (6)$$

$$a = \frac{(\sum x^2)(\sum y) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2} \quad \dots \dots (7)$$

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad \dots \dots (8)$$

$$So^2 = \frac{\sum (a+bx-y)^2}{n-2} \quad \dots \dots (9)$$

$$Sa = So \sqrt{\frac{(\sum x^2)}{n(\sum x^2) - (\sum x)^2}} \quad \dots \dots (10)$$

$$Sb = \frac{So}{\sqrt{\frac{(\sum x^2) - (\sum x)^2}{n}}} \quad \dots \dots (11)$$

where  $\hat{y}$ : estimated  $y$  for a given  $x$

$y$ : measured distance

$x$ : true (reference) distance

$So$ : standard deviation of a measured distance

$Sa$ : standard deviation of scale correction

$Sb$ : standard deviation of additive constant

**5. Results**

The small discrepancies between the measurements of the same quantity indicate that there were no mistakes and that the random errors was too small, which refers to the high precision of the tools [13]. By equations (2) to (5), the deviation of measurements mean values from the corresponding reference distance were computed. Table-2 contains preliminary indicators of the corresponding LDS work. Figure-2 explains how the typical tolerance accuracy of reference distance measurements increases with the measured distance under unfavorable conditions for LDM, as our work conditions. Figures-3 and 4 explain the standard deviation of the LDS1 and LDS2, respectively from the LDM. The small discrepancy between measurements in this test indicate that, specially it is founded between the measurements of the Laser Distance Sensors (LDSs) and that's measured by Laser Distance Meter (LDM), (0.001)m at a maximum amount as the Table-5 explain the results by the equations (2) to (5) which give us the statistical indicators to the (LSD) accuracy with respect to (LDM). In geomatics measurements, using the regression between the measured values and the referenced values is a sufficient expression to explain the systematic error values. For the parameters of the set of equations (6) to (11), Table-5 shows the values of these errors. Table-6 shows the results of regression for the LDS1 and LDS2. Figures-(5, 6) also show these results and the fitted line of regression of the sensors with LDM. The ambient conditions such as temperature, background illumination, target illumination and humidity of both sites, outdoor and indoor, are shown by Table-3. All these computations were computed using MINITAB 17) package software and excel office package.

**Table 4**-Place and Conditions of Measurements

Place	Time	Background Light (lux)	Temperature C°	Humidity %	Target Illumination (lux)	Light description
Outdoor	6:45 AM	37000	30	80	7500	shadow

Indoor	10:30 AM	400	30	60	40	shadow
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**Table 5-Outdoor Measurements by (LDS) and (LDM) (meters)**

Sensor	ID	m <sub>1</sub>	m <sub>2</sub>	m <sub>3</sub>	Reference Distance (D <sub>ref</sub> )
(LDS) 1 (Right)	1	No Read			
	2				
	3				
	4				
	5				
	6				
	7				
	8	12.971	12.970	12.974	12.969
	9	6.268	6.270	6.271	6.285
	10	2.627	2.625	2.630	2.625
(LDS) 2 (Left)	1	No Read			
	2				
	3				
	4				
	5				
	6				
	7				
	8	12.971	12.994	12.991	12.979
	9	6.278	6.279	6.278	6.283
	10	2.617	2.620	2.621	2.626

**Table 6-Indoor Measurements and Statistical Indicators (LDS)**

Sensor	ID	M1	M2	M3	Reference Distance (RD)	dM1	dM2	dM3	mean D	dD: D-RD	S.dev (m) (±)	S.dev (mm) (±)
(LDS) 1 (Right)	1	26.758	26.757	26.758	26.758	0.000	-0.001	0.000	26.757667	-0.000333	2.5E-15	2.51E-12
	2	17.967	17.972	17.966	17.970	-0.003	0.002	-0.004	17.968333	-0.001667	0	0
	3	13.676	13.677	13.677	13.677	-0.001	0.000	0.000	13.676667	-0.000333	2.5E-15	2.51E-12
	4	7.884	7.884	7.882	7.884	0.000	0.000	-0.002	7.883333	-0.000667	1.3E-15	1.26E-12
	5	5.253	5.254	5.255	5.256	-0.003	-0.002	-0.001	5.254000	-0.002000	1.3E-15	1.26E-12
	6	2.715	2.716	2.716	2.715	0.000	0.001	0.001	2.715667	0.000667	3.1E-16	3.14E-13
	7	2.001	2.001	2.001	2.000	0.001	0.001	0.001	2.001000	0.001000	0	0
	8	1.615	1.615	1.615	1.615	0.000	0.000	0.000	1.615000	0.000000	0	0

	9	0.90 1	0.90 1	0.90 1	0.898	0.0 03	0.003	0.003	0.90100 0	0.003000	2.4E-16	2.36E-13
	10	0.75 0	0.74 7	0.75 1	0.748	0.0 02	-0.001	0.003	0.74933 3	0.001333	7.9E-17	7.85E-14
(LDS) 2 (Left)	1	26.8 57	26.8 55	26.8 57	26.86 0	- 0.0 03	-0.005	- 0.003	26.8563 33	-0.003667	5E-15	5.02E-12
	2	18.0 65	18.0 66	18.0 66	18.06 8	- 0.0 03	-0.002	- 0.002	18.0656 67	-0.002333	5E-15	5.02E-12
	3	13.7 89	13.7 88	13.7 89	13.78 9	0.0 00	-0.001	0.000	13.7886 67	-0.000333	1.3E-15	1.26E-12
	4	7.99 3	7.99 4	7.99 4	7.994	- 0.0 01	0.000	0.000	7.99366 7	-0.000333	6.3E-16	6.28E-13
	5	5.14 5	5.14 5	5.14 4	5.146	0.0 01	-0.001	- 0.002	5.14466 7	-0.001333	6.3E-16	6.28E-13
	6	2.71 1	2.71 2	2.71 1	2.711	0.0 00	0.001	0.000	2.71133 3	0.000333	6.3E-16	6.28E-13
	7	1.99 5	1.99 4	1.99 5	1.995	0.0 00	-0.001	0.000	1.99466 7	-0.000333	3.1E-16	3.14E-13
	8	1.61 1	1.61 1	1.61 1	1.610	0.0 01	0.001	0.001	1.61100 0	0.001000	0	0
	9	0.89 3	0.89 3	0.89 4	0.897	- 0.0 04	-0.004	- 0.003	0.89333 3	-0.003667	1.6E-16	1.57E-13
	10	0.65 4	0.65 3	0.65 4	0.661	- 0.0 07	-0.008	- 0.007	0.65366 7	-0.007333	1.6E-16	1.57E-13

**Table 7-Regression Results of (LDS) and (LDM)**

Sensor no.	standard deviation of measured distance (S <sub>o</sub> : mm)	standard deviation of scale correction (S <sub>b</sub> : ppm)	standard deviation of additive constant (S <sub>a</sub> . mm)
(LDS) 1 (Right)	1.35	50.89	0.59
(LSD) 2 (Left)	2.66	99.88	1.16

Using eq. (1) and the data in Table-1, the accuracy for the nominal 100m measurement of LDM will be:

$$\sqrt{2.5^2 + 2.9^2} = \pm 3.8 \text{ mm}$$

We can determine the accuracy of every LDS by adding its additive constant to the measurement accuracy of the LDM mentioned before and adding the scale correction, then the accuracy will be:

Accuracy of LDS1 = ± (4.4mm + 50.89 ppm)

and the accuracy of LDS2 = ± (4.96mm + 99.88 ppm).

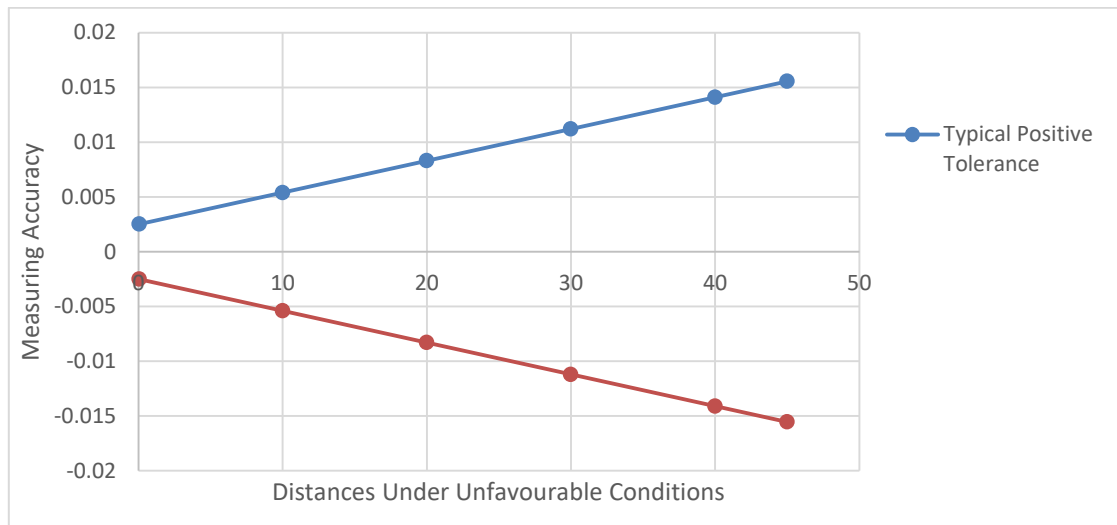
**Discussions**

The factors affecting the laser distance measurement tools are various and influential, but the most affecting factor is the background illumination of the surrounding environments. Table-4 shows the background illumination in (lux) units, where the value for the outdoor were (37000) and the indoor were (400). This high difference confirms the effect of the background. Table-5 shows the measurements outdoor, were they not continue with increases in sun light to increase the background illumination to be the impediment to continue readings or read incorrectly, big difference in readings, while indoor situation, there were no problem to measure properly. A laser sensor, such as an electro optical tool, may be included to affect industrial errors, periodic errors, scale errors, and others.

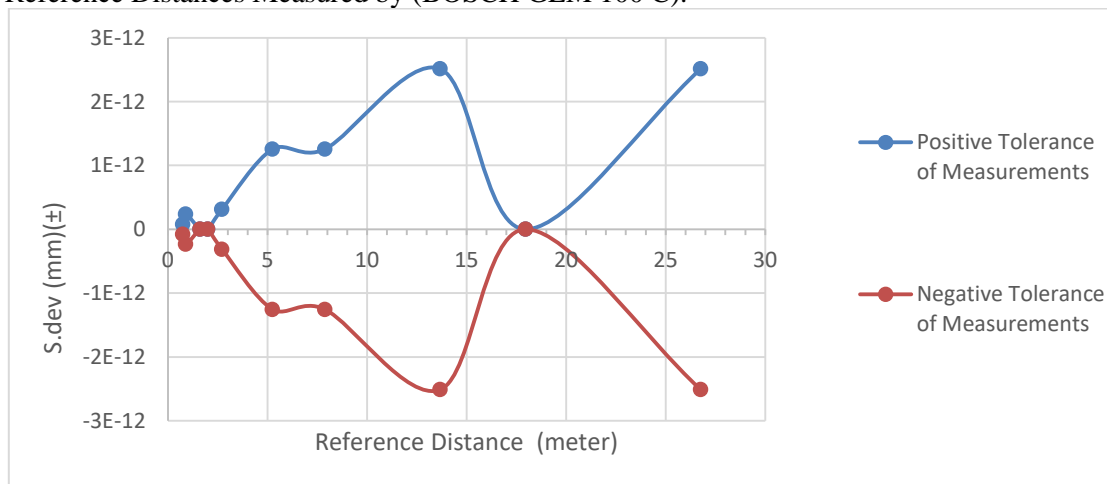
The results in Table-6 show the closest behavior of the LDS to the LDM, through deviation and standard deviation (uncertainty of LDS with respect to LDM ). The maximum standard deviation is



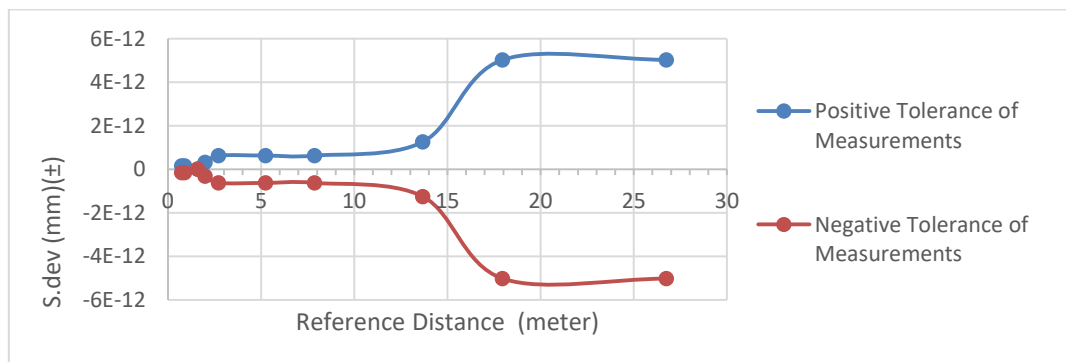
$6 \times 10^{-12}$  mm. The statistical results in Table- 6 give us the initial indicators of the LDS work., where the sensors were functioning as the LDM. Figures-(4, 5) show this matching in work. But Figure-3 explains the behavior of the LDM accuracy; with the increase in distance, the tolerance accuracy increased.



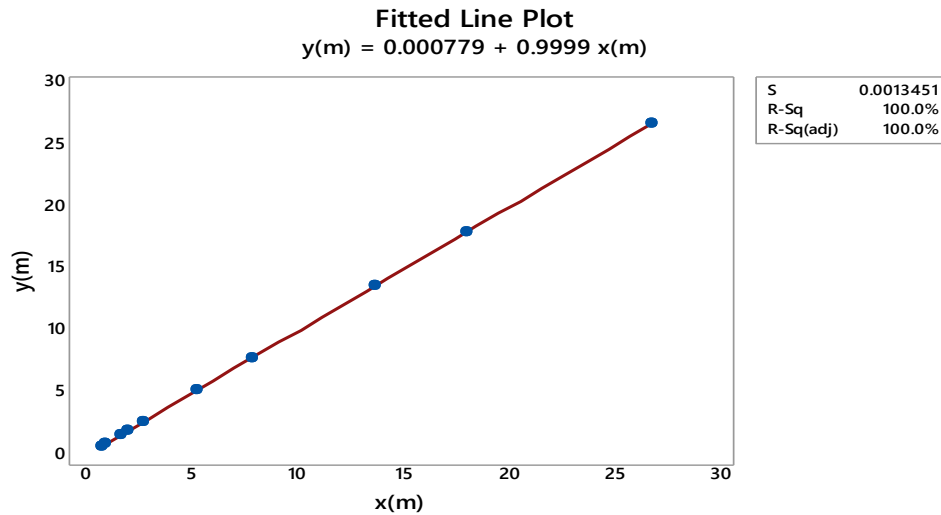
**Figure 3-**Measuring Accuracy For Distances Typical Under Unfavorable Conditions For the Reference Distances Measured by (BOSCH GLM 100 C).



**Figure 4** Standard Deviation For Measured Distances Under Unfavorable Conditions using Laser Sensor No. (1)



**Figure 5-**Standard Deviation For Measured Distances Under Unfavorable Conditions using Laser Sensor No.(2)



**Figure 6-Laser Sensor No.(1)**

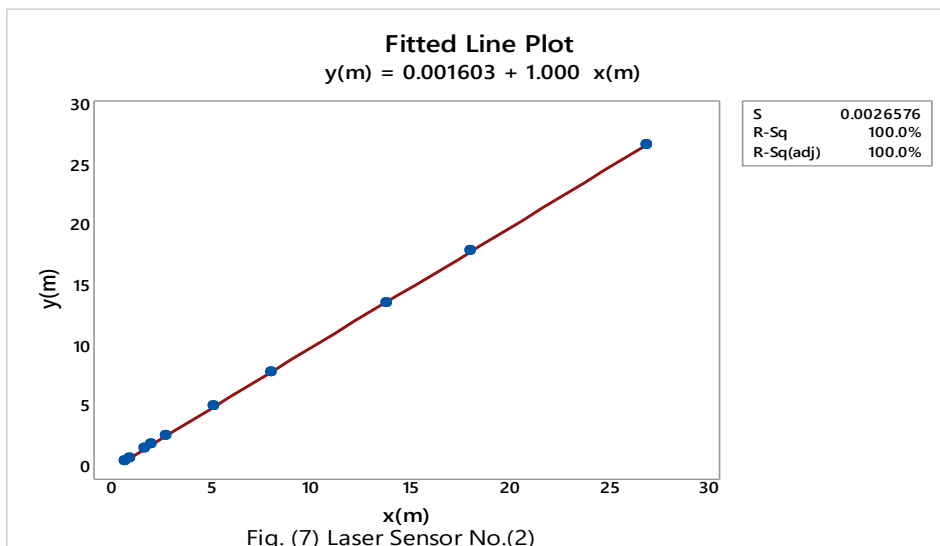


Fig. (7) Laser Sensor No.(2)

**Figure 7-Laser Sensor No.(2)**

**Conclusions**

The good price of the LDS, its small size, the programmability of its built system work, and flexibility of this product to adjust some of its features, make these sensors very useful tools to create methodologies and research abilities for geomatic applications such as land survey applications, photogrammetry applications or others. The variety of manufacturing sources of these sensors prevent their direct use without checking or evaluation. Thus, the evaluation must be the gate to use these sensors. In general, the industry produces them for commercial purposes, but for geomatics demands, therefore, they must be checked. The hardware for the sensors and their requirements such as the clean optics and the zero position of the sensor must be taken into consideration. The statistical check of the sensors with respect to the reference distance meter (LDM) was approximately corresponding to that of the (LDM), but any geomatical work that includes these sensors should determine the accuracy according to the work. The sensors have the same accuracy of LDM adding to the work accuracy. The accuracy in this work showed a value of  $\pm 4.4mm + 50.89$  ppm and  $\pm 4.96mm + 99.88$  ppm for LDS1 and LDS2, respectively, compared with the LDM accuracy which was computed to the full range (100m). The worst situation was followed in computations, while the errors may be not at the same arithmetic sign, where the negative deletes the positive, so the amount of accuracy can be better. Although of that this accuracy very enough for vary applications in geomatics researches like

photogrammetric applications, close or terrestrial range and aerial photogrammetry, for industrial purposes or 3D modeling works.

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