

Experimental and Regression Analysis of Prism and Reflector- Less Edm Measurements Under Variable Field Conditions Using Leica TS16p1R500 Total Station

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EXPERIMENTAL AND REGRESSION ANALYSIS OF PRISM AND REFLECTOR-LESS EDM MEASUREMENTS UNDER VARIABLE FIELD CONDITIONS USING LEICA TS16P1R500 TOTAL STATION

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Abstract:

Electronic Distance Measurement (EDM) is widely applied to carry out topographic surveys and study landforms, land use, river geomorphic change detection, construction layout, dynamic bridge deformations, and documenting the culture heritage. In order to ensure the results of surveying according to the requirements of a particular project, it is important to know the reliability and accuracy of surveying instruments. The achievable accuracy will depend on the instrument used, atmospheric conditions in the line of measurement, and the target employed. In this study, an analysis of prism and reflector-less EDM measurement data based on statistics through a regression approach has been conducted using a Leica TS16 robotic total station. The experimental investigation considered multiple influencing parameters, including prism type, target material, target color, incidence angle, and weather conditions. Statistical analysis was performed using mean error, root mean square error, and regression-based error modeling to examine the relationship between measurement error and observation distance. The results demonstrate that prism-based measurements provide superior accuracy, exceeding reflector-less measurements by approximately 21.77%, particularly at longer distances. Circular prisms exhibited the highest precision, with errors remaining within the millimeter level, while reflector-less measurements showed increased sensitivity to surface properties, incidence angle, and atmospheric variations. Results from regression analysis indicated that prism readings showed consistency with the specified accuracy from the manufacturer across the range of interest, while the reflector-less method displayed increasing discrepancies, especially when atmospheric and geometrical conditions were poor.

Keywords: Electronic total station; Leica TS16P1R500; Prism; Reflector-less; Distance measurement accuracy; Regression analysis, Incidence angle, Atmospheric variations.

29 **Introduction:**

30 In recent times, total stations have been highly important instruments in the process of surveying due to their precision,
31 efficiency, and cost-effectiveness. The total station instrument is extensively employed for surveys involving topographic
32 and terrain analysis as well as land form and land usage, geomorphological change identification in rivers, streams, beaches
33 and hill slope mass movements [1]. This instrument can also be used for building layout operations [2] and bridge
34 deformation monitoring [3] among others.

35 The total station has proven to be very efficient in data gathering due to its incorporation of the EDM and angle measuring
36 components. Furthermore, the utilization of the total station has been widely appreciated in the areas of deformation
37 monitoring, layout and construction, and engineering surveys due to the precision and efficiency associated with data
38 gathering in these instances. This data collection equipment has been preferred to other data collection instruments since it
39 offers an effective combination of precision and simplicity, particularly when dealing with precise data collection within
40 small areas [4].

41 The precision of measurements made using a total station depends not only on the instrument itself but also on the existing
42 environmental conditions along the path of observation, as well as on particular characteristics of the observed object.
43 Therefore, for a precise measurement to be made, all factors that affect it need to be considered [5].

44 However, due to the appearance of a new generation of precise measurement instruments – laser trackers – there has been a
45 reassessment of the place of electronic total stations in surveying. Previously, one of the leading manufacturers of surveying
46 instruments, Leica [6], produced a special series of metrological total stations for industrial use. The High-precision total
47 station Leica TDRA6000 capable of measuring distances up to 300 m with an accuracy of 0.5 mm, and at shorter distances
48 and upon individual calibration of the rangefinder – with an accuracy of 0.2 mm [7], although this series is no longer in
49 production. At present, the Leica TS60, which has a precision of 0.6 mm on a prism for distance measurement, is considered
50 a metrological electronic total station (Leica robotic total stations). The electronic total stations that allow for distance
51 measurements to a prism with an accuracy of 0.4 mm are available in limited quantities. One such total station is a Leica
52 TM50. Thus, currently, almost all precision linear measurements are performed using laser trackers [8].

53 Precision and accuracy of the measurements will be dependent on the accuracy of the surveying method used. In this regard,
54 two principal measurement approaches are generally adopted in modern surveying practice, namely reflective and non-
55 reflective techniques.

56 The first method makes use of the reflection technique through the use of prisms. The signal emitted by the measuring
57 device is reflected by the prism target. Different kinds of prisms can be selected, and selecting the correct prism is essential

to increase accuracy in the measurements performed. There are regular prisms, 360-degree prisms, which can measure at any angle without needing repositioning of the instrument, and mini prisms, which are ideal for close-range work. The type of prism to be used depends on the situation at hand, and using the right one will improve the accuracy of the measurements made. The relevant aspects include the manufacturing of the prisms (materials, construction, etc.), the orientation of the prisms relative to the line of sight of the instrument and the employed electronic distance measuring device [9].

The second technique utilizes non-reflective (reflector-less) methods of measurement, whereby the sensor directly measures the distance between the measuring device and the surface of the object without a prism. The measurement accuracy depends significantly on the physical characteristics of the target object, such as the surface characteristics, color, size, reflectance, and angle of incidence of the emitted beam on the surface. Smooth, light-colored surfaces that are perpendicular to the emitting device tend to produce more accurate results compared to rough, dark, and slanted surfaces [10, 11]. Nevertheless, the reflector-less method boasts some major advantages over the reflective technique, especially when it is impractical to position a prism.

The reflector-less total station is used in many fields because of the accuracy and speed of measurement in the automated measurement process [12]. This measurement method does not use any prism and can just reflect off anything. The most important feature of the reflector-less total station is that, it allows measuring the inaccessible points. There are several factors affecting the accuracy of this measurement method, such as the strength of the reflected signal, the intensity of the returning signal, the distance between the total station and the measured point, the angle of incidence of the reflected signal and the angle of inclination[13].

The objective of this study is to assess and analyze the accuracy of distance measurements through the use of RTS16 P1 R500 total station using different measurement methods and environments. In this study, the findings of various prism tests are presented concentrating on modern prisms including circular prisms (Gph1p High Precision), 360° (Reflector Ads360-13, Apt3), and mini prism (PE640b 64mm) in relation to the accuracy of measurements. Another objective of this study is to analyze the accuracy of reflector-less measurement. Moreover, this study is also concerned with the impact of atmospheric factors like temperature, pressure and humidity on distance measurements. Four different static trial tests were conducted. The first test was regarding the effect of different distances on the precision of measurement. The targets were set within the distances of 12m up to 215m. The second test is about the impact of prism types and prism colors on the precision of measurement. The third test was on the effect of the angle of incidence and the fourth test was on the effect of different weather conditions.

This paper highlights the combination of geometric, environmental, and surface factors in an experimental setup with the use of Leica TS16P1R500 robotic total station. As opposed to the traditional approach of assessing the accuracy of measurement, the present study employs regression analysis for determining the correlation between errors of measurement and the distances observed in both prism and reflector-less modes. It is also concerned with determining the level of deviation of reflector-less observations from EDM specifications by the manufacturer under poor environmental conditions, high incidence angle, and varied target characteristics. Furthermore, the study contributes to the characterization of uncertainty in reflector-less EDM measurements through residual analysis and error modeling.

During the experiments, great care was taken to position the front face of each prism correctly relative to the line of sight of the total station. Statistical analysis included calculating the average values of the data obtained and their standard uncertainty, and root mean square error (RMSE) was calculated when a true value for comparison purposes existed. The existence of a true value for RMSE calculation was ensured through the presence of a precisely calibrated test site whose coordinates were known.

1. Literature Review

The performance and accuracy of TS measurements have been thoroughly researched in numerous scientific publications, especially regarding both reflective and non-reflective types of measurements. Previous research works have analyzed various affecting factors such as instrument parameters, environmental effects, target properties, and geometry of measurement using of initial models total stations instruments.

Initial research, for instance [14] examined the influence of target colors on the accuracy of readings obtained from different total stations. It was found out that the use of white target yields readings which are comparable to the manufacturer's specifications; this shows the significance of reflectance. On the same note, [15] explored the role played by obstacles within the line of sight of total stations such as plants and partial prisms. The research revealed that obstacles closer to the TS significantly influenced its precision than those that are far away.

However, [13] went further by examining the impact of the environmental factors including sunlight and battery size along with the surface characteristics and inclination angles on total stations and digital levels. The outcomes of their study show that the accuracy of the measurement depends not only on the environmental factors but also on the operational factors of the instruments themselves. Another similar study carried out by [16] investigated the accuracy of reflector-less measuring methods and concluded that they were more prone to mistakes than prism methods.

Further studies focused on the role of target characteristics and measurement geometry. According to [10], research was carried out to test the effect of the surface material, target size, and the angle of incidence, which showed that target size is

115 an important factor when the angle of incidence is within the range of 15°-30°. In addition, [17] explored reflector-less
116 measurement accuracy, where emphasis was placed on surface material, surface color, and performance of batteries among
117 other factors.

118 Furthermore, prism characteristics have been examined as well. Specifically, [18] considered the effects of the shape and
119 direction of prisms on automated total station observations, proving that both of these parameters strongly influence
120 precision apart from atmospheric disturbances. It should be noted that the use of adequate prism direction and prism itself
121 are essential for obtaining precise measurements. In addition, [11] considered the influence of beam divergence and angle of
122 incidence in reflector-less measurements.

123 Some of the more recent studies include the effects of laser signal and surface contact on the accuracy of measurement.
124 Specifically, according to the study by [19], tests were performed using a variety of materials and found that dark and dull
125 surfaces yielded larger errors than bright and reflective surfaces.

126 In spite of this significant number of scientific studies, some weaknesses can be outlined. First, most prior research
127 examined various independent parameters that influence the measurement precision without taking into account how they
128 would interact in an integrated experiment. In addition, many researchers used total stations of earlier models that could not
129 reflect the performance of contemporary high-precision total stations. Thus, it is necessary to undertake a detailed research
130 that will examine the performance of Leica TS16P1R500 total station in reflector and reflector-less mode taking into
131 account the multiple parameters affecting its performance.

132 A regression analysis method for assessing prism and reflector-less EDM measurements with regard to environmental and
133 geometric factors was introduced in this research through the use of Leica TS16 robotic total station. This innovative
134 method is not only based on the descriptive measures of accuracy but rather also considers the correlation between the
135 experimental results obtained from the measurement process and the model provided by the equipment manufacturer which
136 consists of constant error + ppm.

137 **2. Test instrumentation:**

138 The instruments and equipment used in the present study have been chosen on the grounds of extensive application in
139 engineering surveys and their suitability for contemporary requirements of accuracy. The total station along with its
140 accessories is an indispensable tool for geodesy and falls under internationally recognized standards such as ISO 17123
141 [20]. This makes it possible to evaluate the accuracy of measurements according to specific methodologies, which makes
142 their choice justified in terms of assessment of measurement accuracy.

143

2.1. Total Stations:

Total Station is the mixture of ‘Theodolite’ and ‘Electronic Distance Meter’ (EDM) [21]. The ‘Theodolite’ determines the angle according to the reading on the two circular scales while the ‘EDM’ calculates the distance on the basis of the laser pulses emitted by the prism or other objects. It is termed as ‘direct reflection’ or ‘reflector-less’ without using the prism. Prism constant, air temperature and air pressure are some of the factors to be considered while using TS. The total station used in this research was A high-precision Leica TS16P1R500. The Leica TS16P1R500 total station is a refurbished, high-precision instrument designed for the demanding needs of land surveying and construction projects. It is designed to operate under diverse conditions such as rainfall, fog, dust, sunlight, heat mirage, and reflection, guaranteeing accuracy of operation when deployed in the field. The latest calibration was performed on 7th November 2024, thus keeping its precision up to date (as seen from Fig. 1). Technical details of the total station are presented in Table 1 [22]. A weather station SKYMASTER (no. 21244) was used for measurement of temperature, atmospheric pressure, and humidity.



Fig. 1. A high-precision Leica TS16P1R500 Total Station used in the study

Table 1. Technical specifications of the Leica TS16 P1 R500 Total Station [22].

Angle measurement accuracy	1 "		
Distance measurements range	Prism	0.9 m – 3500 m	
	Non-prism	0.9 m – 500 m	
Distance measurements accuracy	Prism	1mm + 1.5 ppm	
	Non-prism	2 mm + 2 ppm	
Overview camera	Sensor	megapixel CMOS sensor	
	Field of view	19.4°	
	Frame rate	Up to 20 frames per second	
Target aiming range / Target locking range	Circular prism (GPR1, GPH1P)		1,500 m / 1,000 m
Power search range / search time	360° prism (GRZ4, GRZ122)		1,000 m / 1,000 m
	360° prism (GRZ4, GRZ122)		300 m / typically 5 s
Processor	TI OMAP4430 1GHz Dual-core ARM® Cortex™- A9 MPCore™		
Environmental specifications	20°C to +50°C, IP55, 95% non-condensing		
Battery Life	8 hours	Data Storage	2 GB
Operating System	Windows EC7	Field Software	Leica Captivate

2.2. Targets:

For this research three types of Leica prism targets as shown in Figure 2a-2c were used to evaluate the effect of different types of prism on accuracy of measurements carried out using Leica TS16P1R500 total station in both prismatic and non-prismatic options. While reflector sheet, installed on specially designed base as illustrated in figure 2d, was used for non-prismatic options [6]. The types of prism used are as follows: Gph1p High Precision Circular Prism, manufactured by Leica Geosystems (Professional Series 5000), PE640b 64mm Mini Prism, 360 Surveying Prism Reflector Ads360-13 Apt3 and Reflector sheet.

2.3. Special Supporting Base:

The special support base had to be prepared in order to correctly position the targets. In order to prepare a simple design of the fastening support base, there would be a screw on the rear plane in such a way that would facilitate easy attachment of the fastening material. The design was of stainless steel and ensured that the inner part of the front plane was always located at the center of the screw on its lower part. A horizontal circle was added in order to facilitate rotation of the target to the correct incidence angle of the laser beam on the target surface as shown in Figure 2d. Calibrations of the special base were done using the reflector sheet. Distance measurements of 10 and 50 meters were taken using the steel tape and total station with normal prism. The prism was replaced with the special base which had the reflector sheet mounted on it. Distance measurements were taken again and compared with the previous measurements done using the prism and steel tape and deviations were noted. The deviation value had to be subtracted from each reading before comparing it with readings of other prisms. So the specific support base was calibrated and ready for experiments.



(a)



(b)



(c)



(d)

Fig. 2. Targets used with total station in the study. (a) Gph1p High Precision Circular Prism, (b) The PE640b 64mm Mini Prism, (c) The 360 Surveying Prism Reflector Ads360-13, Apt3 and (d) Reflector sheet.

3. Methodology:

The experimental procedure used is the following:

- 1) The base line is defined using steel tape, with distinct nails placed along the line on the road in the territory allocated to the Faculty of Engineering of our University, as illustrated in Figure 3. There is a wall parallel to the determined line, positioned at an approximate distance of 3 m from it. Calibration of the spatial reference baseline was done with the assistance of Leica AT 403 laser tracker. However, due to the limitation in the measurement range of the laser tracking system on the reflector not exceeding 160 meters, measurements were conducted in stages for certain points from A1 to A10 to keep the error in check. The accuracy of determining the reference lengths was within 0.1 mm.
- 2) The Leica TS16 P1R500 total station is positioned at first point A1, and then adjustments are made to use the fine distance mode.
- 3) The circular prism Gph1p is centered on the next point. After setting the instrument to the prism mode, the distance between the instrument and the circular prism is measured.
- 4) The circular prism is removed from the tribrach and the mini prism PE640b 64mm is installed. During these changes the telescope of the instrument is not moved and after setting the instrument in prism mode, the distance is re-measured and then the mini prism is removed and 360° Surveying Prism Reflector Ads360-13 Apt3 installed and distance re-measured.
- 5) Steps 3 and 4 are repeated for the next points, *i.e.* distances 12 m, 25 m, 48 m, 74m, 96 m, 120 m, 145 m, 168 m, 192 m and 215 m.
- 6) The 360° Surveying Prism is removed from the tribrach and the special base is attached to it. The tribrach is fixed on the first point A1. Then the reflector-less target is placed on the base and the distance between the total station and the reflector-less sheet is measured when the instrument is set in reflector-less mode.

199 7) Steps 6 is repeated for the next points, *i.e.* distances 12 m, 25 m, 48 m, 74m, 96 m, 120 m, 145 m, 168 m, 192 m and 215
 200 m.
 201 Prism measurements were taken independently at different time intervals in auto guidance mode, 15 times during the left
 202 turn and 15 times during the right turn, and in reflector-less mode, 30 times during the turn.
 203 The Root Mean Square error was calculated by taking several readings of the distance. The various distances measured from
 204 the instrument to the target include 12, 25, 48, 74, 96, 120, 145, 168, 192 and 215 m. The tests were carried out in day time,
 205 natural light and at the temperature of approximately 32° C.



Fig. 3. Study area

208 4. Results and Discussion:

209 The differences between the measured distances on the prism (D_p) or on the reflector-less target and the reference distances
 210 values (D_r) were calculated using Equation (1):

$$211 \quad V_i = D_p - D_r \quad (1)$$

212 The acceptable value of V is given by the Equation (2) (Khalil, R., 2015) for the desired confidence level (x):

$$213 \quad -x \cdot \sigma_V \leq V \leq x \cdot \sigma_V \quad (2)$$

$$214 \quad \sigma_V = \sqrt{\sigma_{D_p}^2 - \sigma_{D_r}^2} \quad (3)$$

215 where:

216 σ_{D_p} = error of the distance measurement on the prism or reflective sheet according to the manufacturer;

217 σ_{D_r} = error of the reference distance measurement.

218 For each position of marks, the mean square error will be calculated by using formula:

$$m_d = \sqrt{\frac{\sum_{i=1}^n V_i^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^n (D_p - D_r)^2}{n-1}} \quad (4)$$

where, n is the number of measurements.

4.1. Studying the Effect of Prisms Type:

In order to investigate the influence of prism type on measurement accuracy and precision, several measurements were conducted during the day using a Leica TS16 P1 R500 Total Station in reflective mode. This has involved the use of three types of prism such as the high precision circular prism (GPH1P), mini prism (PE640B) and 360-prism (ADS 360-13 APT3). The atmospheric parameters for the Leica TS16 P1 R500 Total Station were input immediately during the measurement process. Figure 4 and table 2 illustrate the results of a comparison of the lengths measured by the Leica TS16 P1 R500 Total Station in reflective mode with their reference values for each prism. The Root Mean Square Errors of measured distance using the Leica TS 16 P1 R500 Total Station in reflective mode with all three types of prisms are shown in the figure 5, while the inclination angle for all three types of prism is equal to zero.

- With the increase of distance between the total station and the target, the error in measured distance also increases.
- The error of measured distance of circular prism were less than 1mm with Root Mean Square error up to 0.2 mm for distance less than 100 m and no more than 1.5 mm with RMS error 0.04 mm for distance arrived to 200m, and differences of circular prism is smaller than the error of observed distance in other types.
- for 360° prism it can be seen that, it has the largest difference and a cycle error with about 0.5 – 2.5 mm amplitude with RMS errors of 0.5 mm.
- At a short distance between total stations and prism, the type of prism used does not have a noticeable effect on the precision or repeatability of measurements. However, with the increasing the distance, the effect of prism type becomes observable. It has been confirmed that the Leica TS16P1R500 presented better accuracy at longer distances using a circular prism than when a mini prism or a 360 prism is used.
- The deviations of the measured values from the reference will not exceed $\pm\Delta/2$, means that the deviations no more than 0.25 mm when using Leica TS16 P1 R500 Total Station in prismatic option.

Table 2 Comparison results of measured lengths using different prisms

Distances, m	Differences from reference values, mm			Mean, mm	Min, mm	Max, mm	$\Delta/2$, mm
	GPH1P	PE640b	Ads360-13 Apt3				
12	0.4	0.45	0.5	0.45	0.4	0.5	0.10
25	0.5	0.55	0.65	0.57	0.5	0.65	0.08
48	1.0	0.9	1.1	1.0	0.9	1.1	0.10
74	0.7	0.8	0.9	0.8	0.7	0.9	0.10
96	0.7	0.9	0.8	0.8	0.7	0.9	0.10

120	1.0	1.1	1.3	1.13	1.0	1.3	0.15
145	1.4	1.4	1.6	1.47	1.4	1.6	0.10
168	1.6	1.8	1.7	1.7	1.6	1.8	0.10
192	1.5	1.6	1.8	1.63	1.5	1.8	0.15
215	1.6	1.9	2.1	1.87	1.6	2.1	0.25

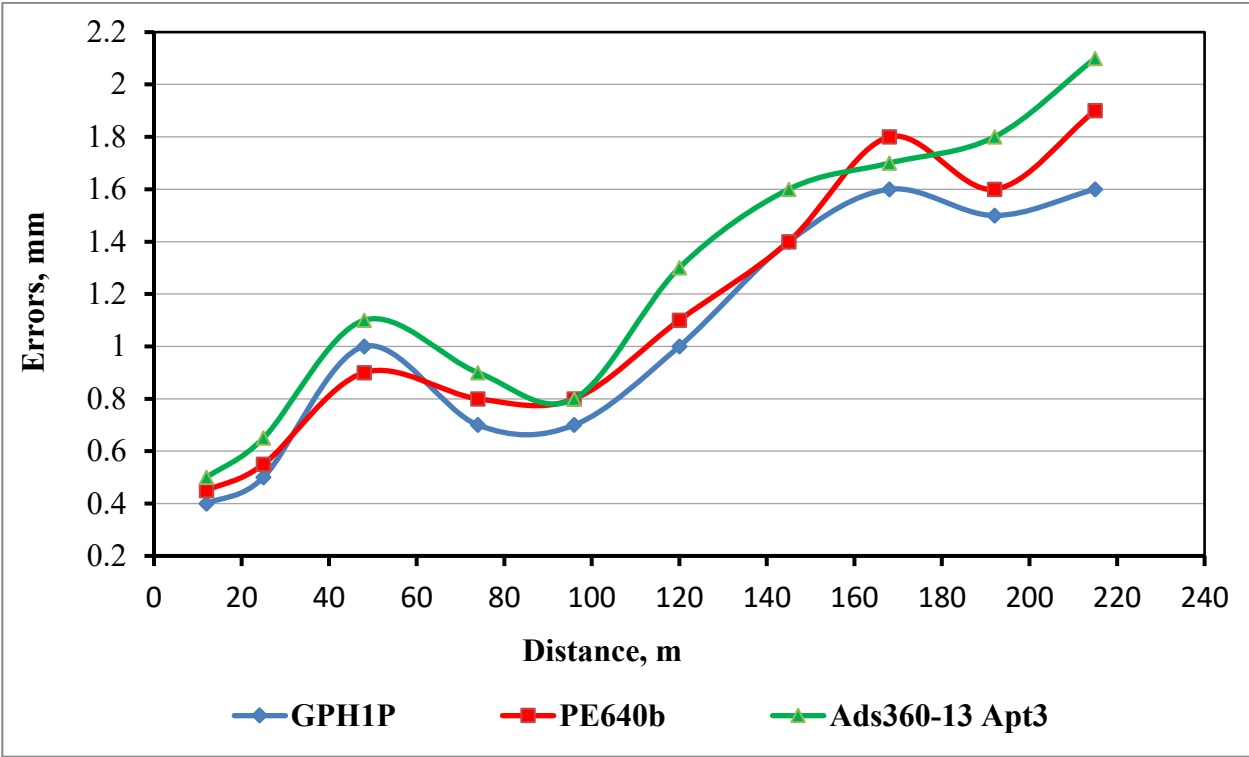


Fig. 4. Results of comparison of measured lengths by the Leica TS16P1R500 total station in reflective mode with their reference values

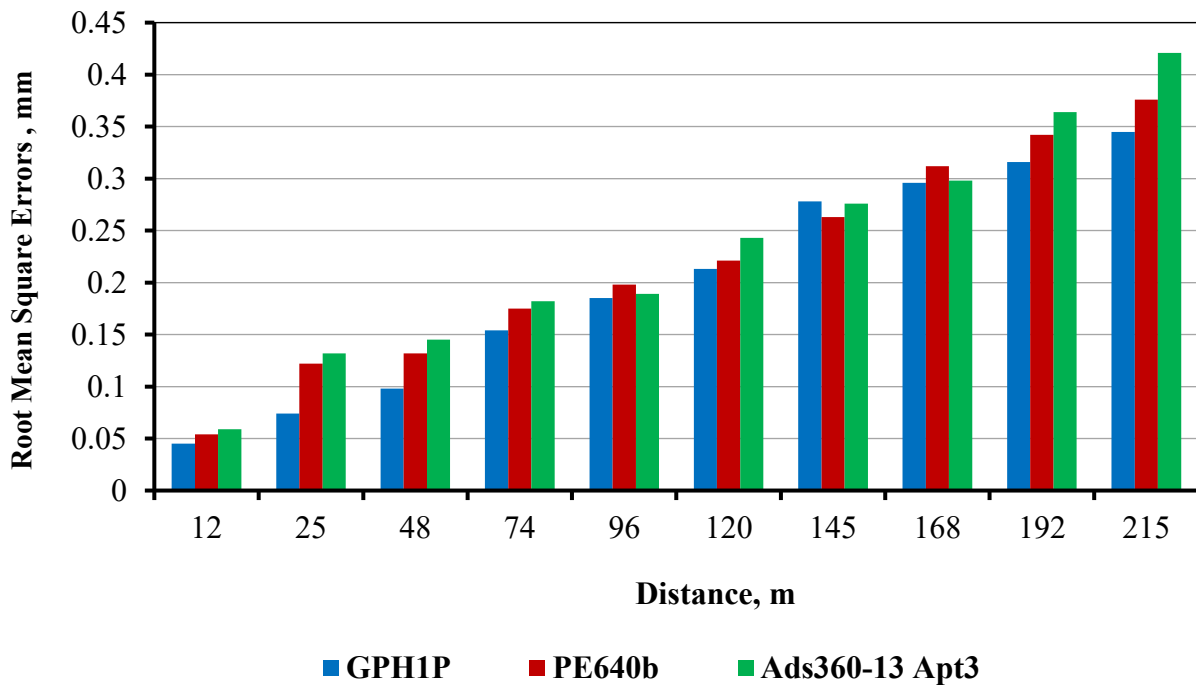


Fig. 5. Root Mean Square Error of measured distance in prismatic option with Leica TS16P1R500 TS

4.2. Studying the Reflector-less Mode:

Reflecting-less measurements have only been incorporated into total stations quite recently. They can enable easy safe and accurate measurements as long as the correct use of them is known and their drawbacks taken into account. The range of these measuring instruments has been increasing and currently some of them can reach 1500 meters on white surfaces or hundreds of meters even on darker surfaces. This should be plenty as it is hard to accurately aim at the measuring object on the distance of several hundred meters due to the divergence of the beam of light.

The research on reflector-less instruments' accuracy will be divided into several segments: test measurement on different materials and test measurement on different colors.

4.2.1. The Effect of Material of Reflecting Surface:

The aim of this section is to investigate the effect of different types of surfaces on the distance measurements made with the help of the reflector-less method. All the tests were conducted outdoors under approximately 34 degrees Celsius at distance of 12 m as the nearest one and 26 m. The targets were affixed to a special basis intended for the tests at equal distance from the total station and with the angle between the measuring signal and measuring object as being close to the perpendicularity. The measurements were made from gypsum boards, wood, plastic, brick, ceramics, concrete, and metals. Indeed, there were repeated measurements conducted for different surfaces which resulted in 15 readings taken in total for each surface to be able to calculate the root mean square errors when utilizing the construct with the total station Leica

TS16P1R500 and reflector-less capability at a distance of 12 meters. The distance of 26 meters was also utilized in a similar way. The results of the distance calculations utilizing the total station Leica TS16P1R500 and reflector-less mode at the distances of 12 and 26 meters are summarized in Table 3.

By analyzing the data obtained in table 3, it is concluded that the material of the surface greatly influences the performance of the observation process using a reflector-less total station. For instance, metal target material has the least reflection and the brick and wooden targets have the best reflections with mean errors of 1mm and 1.2mm for 12m and 26m distances respectively. Root mean square error is reached 0.2 mm for wooden targets.

Table 3 Mean values and root mean square errors for measured distances using different target material with Leica TS16P1R500 total station in reflector-less mode in mm

Target	Distance = 12 m				Distance = 26 m			
	Min	Max	Mean	Root Mean square error	Min	Max	Mean	Root Mean square error
Gypsum board	-2.1	1.85	1.12	0.214	-2.2	2.1	1.45	0.254
Wood	-2.80	1.80	0.95	0.156	-3.0	2.2	1.12	0.201
Plastic	-1.60	3.80	1.62	0.225	-1.8	2.7	1.85	0.236
Break	-1.65	2.65	1.05	0.157	-2.0	2.55	1.16	0.198
Ceramics	-3.0	2.20	1.20	0.204	-2.8	2.7	1.75	0.225
Concrete	-2.70	2.60	1.35	0.245	-2.5	2.8	2.01	0.267
Metal	-2.20	2.60	2.55	0.356	-2.4	3.1	2.85	0.425

4.2.2. The Effect of Different Colors of Reflecting Surface:

The effect of the color of the target that reflects the ray of light will greatly influence the precision of reflector-less total station measurement. In order to investigate the differences due to colors, the experiments were conducted outdoor on one of the specific days when the temperature was approximately 34°, on which seven wooden targets with different colors (white, yellow, red, brown, black, gray and blue) were set at various distances (12 m, and 26 m) from the Leica TS16P1R500 total station. The inclined angle from the target to measuring signal was nearly perpendicular. With regards to each color target, 15 measurements of each distance were performed using TS16P1R500 total station in reflector-less mode. As a result, the Root Mean Square error of each target was determined. The Root Mean Square error for measured distance by TS16P1R500 total station in reflector-less mode on different colored surfaces (white, yellow, red, brown, black, gray and blue) were presented in table 4, where the inclined angle from the targets was made to be approximately equal zero.

Table 4 Root mean square error for measured distance using different wooden target colors with Leica TS16P1R500 total station in reflector-less options

Wooden Target Colors		White	Yellow	Red	Brown	Black	Gray	Blue
Root Mean Square Error (mm)	12 m	0.156	0.180	0.196	0.201	0.216	0.185	0.281
	26 m	0.201	0.221	0.236	0.282	0.354	0.211	0.326

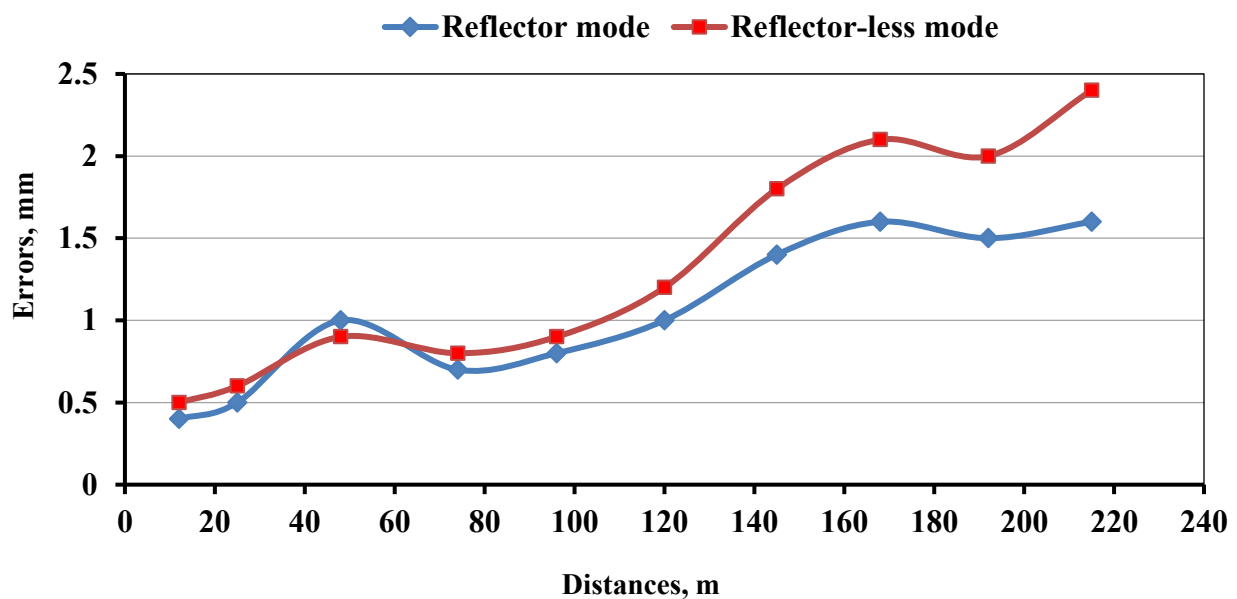
287 From the above table 4, it could be observed that the accuracy of the white surface is superior to any other while the black
 288 surface has the lowest accuracy among all other color surfaces. This could be explained by the fact that the white surface
 289 has the highest reflectivity compared to all others for the laser beam of the total station without reflector.

290 4.3. Comparison the Accuracy of Leica TS16P1R500 Total Station Observations with Reflector and Reflector-Less

291 Modes:

292 In order to test the accuracy of TS16P1R500 total station for distance measurement with reflector-less ability and with
 293 prismatic option, the baseline was selected between two fixed points whose distance equal to or more than 200 meters. The
 294 total station was fixed on the first station of the baseline A₁, and ten marks were positioned at different distances from the
 295 instrument: 12 m, 25 m, 48 m, 74 m, 96 m, 120 m, 145 m, 168 m, 192 m, and 215 m. Then, the distance from the instrument
 296 to each mark was measured 15 times with reflector-less ability by using a white wooden target as the best one according to
 297 sec. 4.2. When completing the process of reflector-less measurements, the software of the instrument was switched to
 298 reflector measurements, and the process of distance measurements was repeated with the same targets, with using a high-
 299 precision circular prism Gph1p as the best one according to sec. 4.1.

300 The results from a comparative study of the measurements recorded through the Leica TS16 P1 R500 total station in both
 301 reflective and non-reflective settings with respect to their references values were outlined in Figure 6. The comparison of
 302 the Root Mean Square error of measured distances using the Leica TS16P1R500 total station in reflective and non-reflective
 303 mode, along with their references values, was presented in Figure 7.



304

Fig. 6. Comparison of measured lengths by the Leica TS16P1R500 total station in reflector and non-reflector mode with their reference values

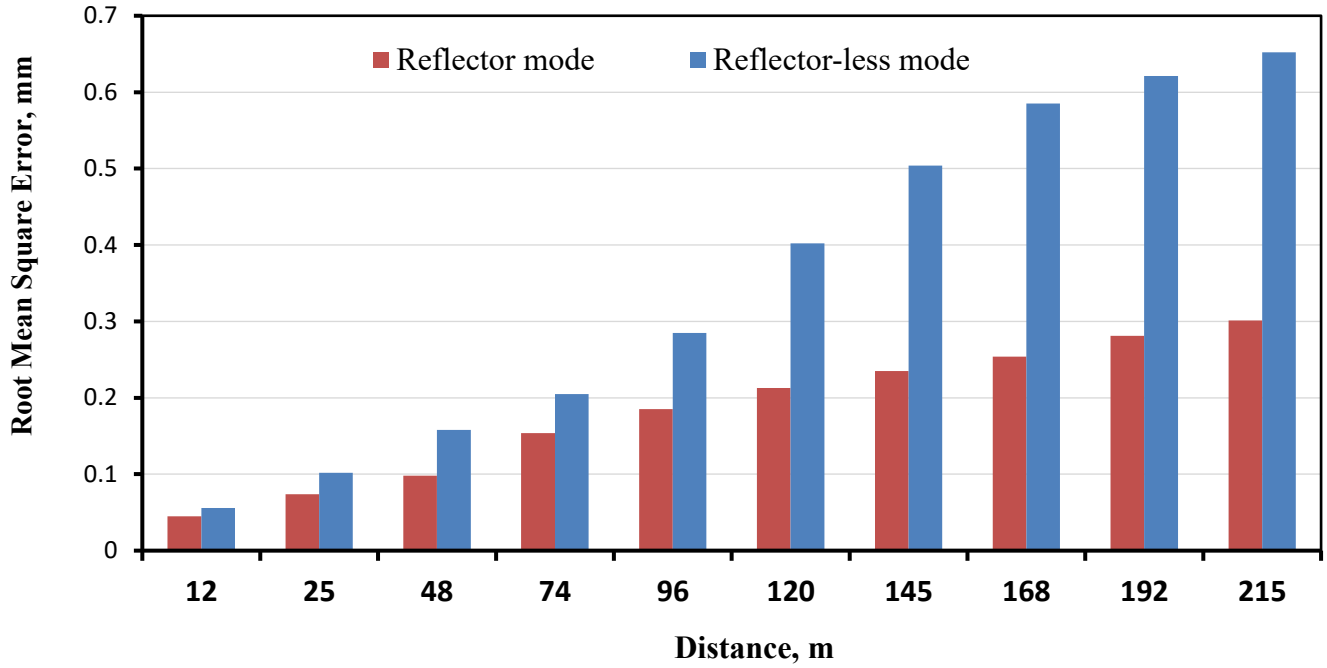


Fig. 7. Comparing the accuracy of Leica TS16 P1 R500 total station observations for measuring distance with reflector and reflector-less mode

The results derived from various graphics in this case demonstrate that, the Root Mean Square error in the distance determination using prism measurement operation is less than that of the reflector-less operation. This is due to the difference in the strength of the signals detected with the reflector-less mode and prism measurement mode. Nevertheless, the deviation in distance values measured in reflector-less operation is greater than in prism mode, albeit it remains random. It can be concluded from the presented graph that the accuracy of observation obtained using reflector ability is 21.77% better than that with reflector-less ability.

4.3.1 Statistical Regression Analysis of Distance Measurement Errors:

To investigate the performance of the Leica TS16P1R500 total station and determine whether the experimental results are consistent with the specifications provided by the manufacturer, a regression analysis was conducted using statistical methods for both the prism and reflector-less measurements.

Two separate regressions were done on the prism data and on the reflector-less data based on the experimental results derived from the calibration of the baseline data as in figure 8. The equations for the regressions are presented below:

Prism Measurements

$$E_p = 0.3294 + 0.0064 D, \text{ with } R^2 = 0.9344 \quad (5)$$

324 Reflector-less Measurements

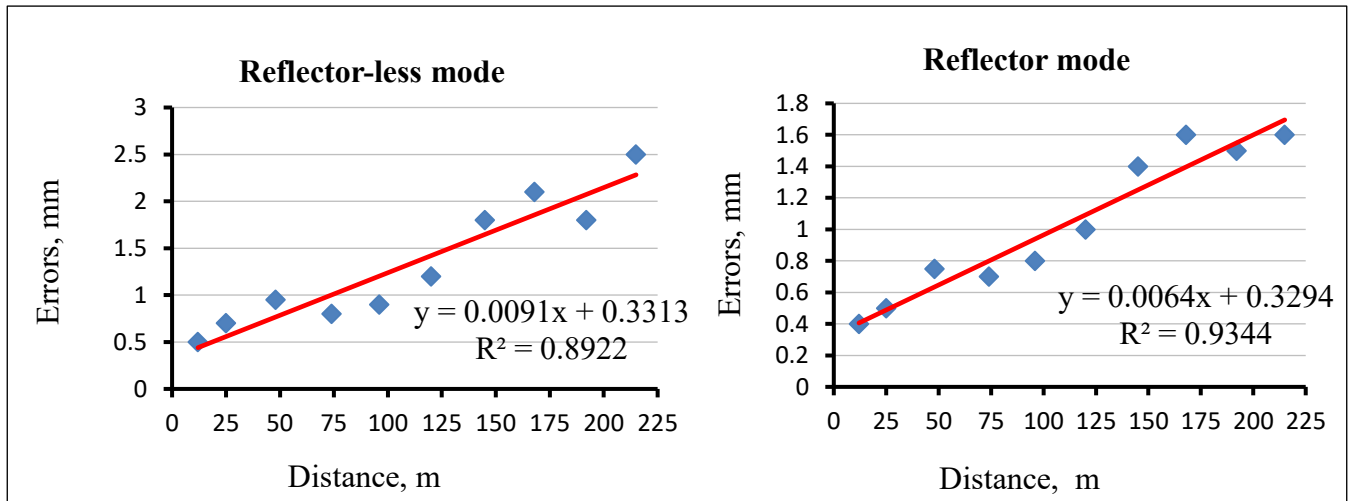
$$325 \quad E_{n-p} = 0.3313 + 0.0091 D, \text{ with } R^2 = 0.8922 \quad (6)$$

326 where:

- 327 • E represents the measured distance error (mm),
- 328 • D denotes the observation distance (m),
- 329 • R^2 coefficient of correlations.

330 This models corresponds to the widely adopted constant-plus-ppm error model used in EDM instrumentation specifications.

331



332

333 Fig. 8. Linear regression analysis of prism and reflector-less measurement errors versus observation distance

334 The regression models obtained show that the distance-dependent part of reflector-less observations is relatively bigger
 335 compared to the distance-dependent part of prism observations. The result proves that reflector-less observations are highly
 336 susceptible to changes in observation distance and environment conditions. The observations performed using prisms show
 337 high consistency with the accuracy model provided by the manufacturer in Table 1. However, for reflector-less
 338 observations, deviation from the accuracy model of the manufacturer was observed especially at long distances and bad
 339 environmental conditions.

340 4.3.2. Residual Analysis of EDM Observations

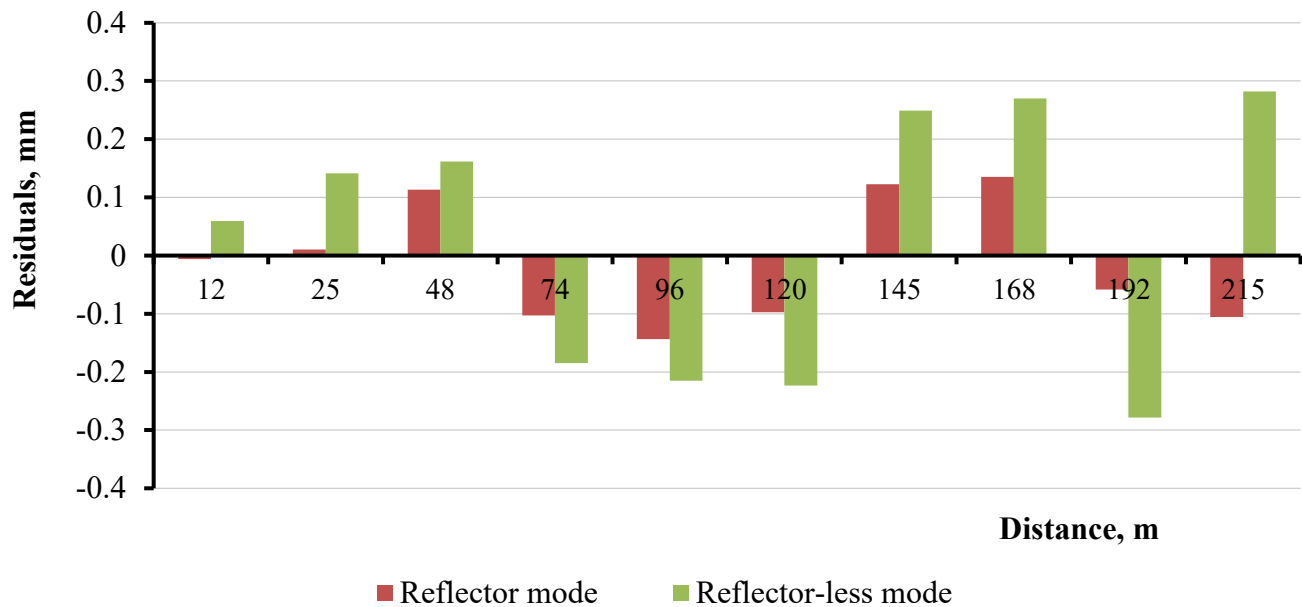
341 For an evaluation of the sufficiency of the regression models and to study the statistical properties of the EDM
 342 measurements, the residual analysis was done for the readings made with the prism as well as reflector-less methods. The
 343 residuals were determined by subtracting the predicted values from the observed values of errors as in formula:

$$344 \quad \text{Residual} = E_{\text{observed}} - E_{\text{predicted}}$$

345 The analysis of residuals in Figure 9 revealed that observations made with the use of prism demonstrate relatively stable
 346 distribution of residuals, which are randomly scattered on either sides of the zero line with residual values varying from
 347 about -0.12 mm to $+0.12$ mm. Such a distribution of residuals confirms that there is good consistency between the
 348 measured values and regression equation suggested, demonstrating that prism measurements are stable within the selected
 349 distance range.

350 On the other hand, the distribution of residuals obtained from reflector-less observations shows that residual values vary
 351 from about -0.3 mm to $+0.3$ mm. In addition, it was also noted that residual values increase progressively for distances
 352 greater than about 100 m, revealing increased uncertainty in reflector-less observations with increasing measurement
 353 distance. This phenomenon occurs due to atmospheric attenuation, beam divergence, and surface reflection phenomena.

354 Further, through analysis of the residuals, it was clear that prism-based observations maintain their statistical consistency
 355 with the EDM manufacturer's specification within the considered distance interval while the reflectorless-based
 356 observations show increasing deviations from the model specification amid environmental and geometrical constraints.



357
 358 Fig. 9. Residual distribution of prism and reflector-less regression models

359 4.4. Studying the Effect of Angle of Incidence:

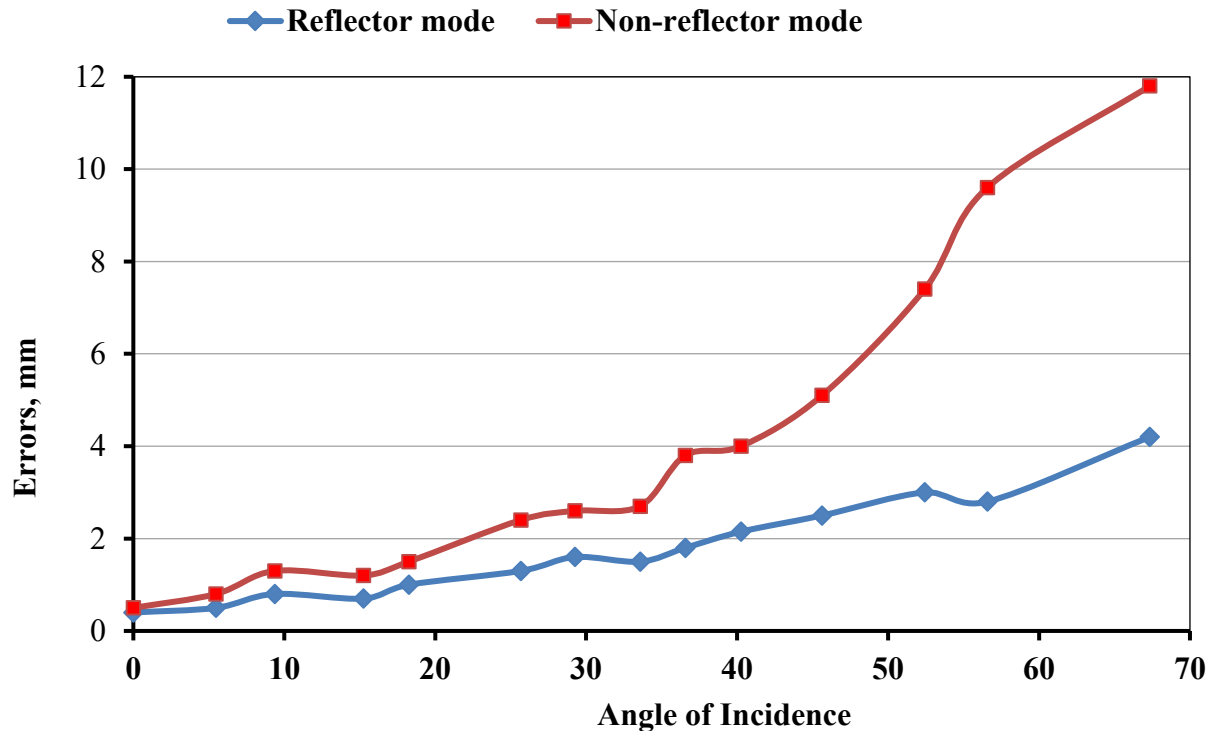
360 One of the significant tests was the angle of incidence test, which involved the reflector-less measurement of an object from
 361 a location that was not perpendicular to the object surface. Nevertheless, this scenario is quite prevalent in surveying
 362 observations. In this instance, there are two probable sources of error. First, there would be no coincidence between the
 363 optical axis of EDM and theodolite, meaning that the alignment of the measurement signal would not match the alignment

364 of the optical axis measurement signal. Second, the magnitude of the error would be higher with increased distance between
 365 the instrument and the target owing to the size of the measuring signal.

366 The experiments was conducted within the college compound on the smooth precast white concrete structure. The
 367 equipment was positioned at a distance of only 12 meters from the plane wall, which minimized the divergence errors that
 368 would occur at an increase in distances. The measurements were taken while facing left and facing right, taking the average
 369 in an attempt to identify any difference in results that might have been brought about by the position of the instrument [24].

370 Test requires determination of the Root Mean Square error of 15 observations at each angle of incidence in Leica
 371 TS16P1R500 total station by means of its prismatic option and reflector-less option. The observations range varies
 372 depending on the angle, which is 0, 5.47, 9.354, 15.237, 18.256, 25.657, 29.254, 33.568, 36.567, 40.258, 45.625, 52.425,
 373 56.578, and 67.334 degrees. The range provided is sufficient taking into account the results of the experiment.

374 Difference between distances observed by total station in both cases of measurement (with and without prism) compared to
 375 the reference value depending on inclination angles is shown in figure 10. Figure 11 illustrates the accuracy of prismatic
 376 observation and reflector-less observation at various angles of incidence.



377
 378 Fig. 10. The differences for measured distance by Leica TS16P1R500 in different inclined angle

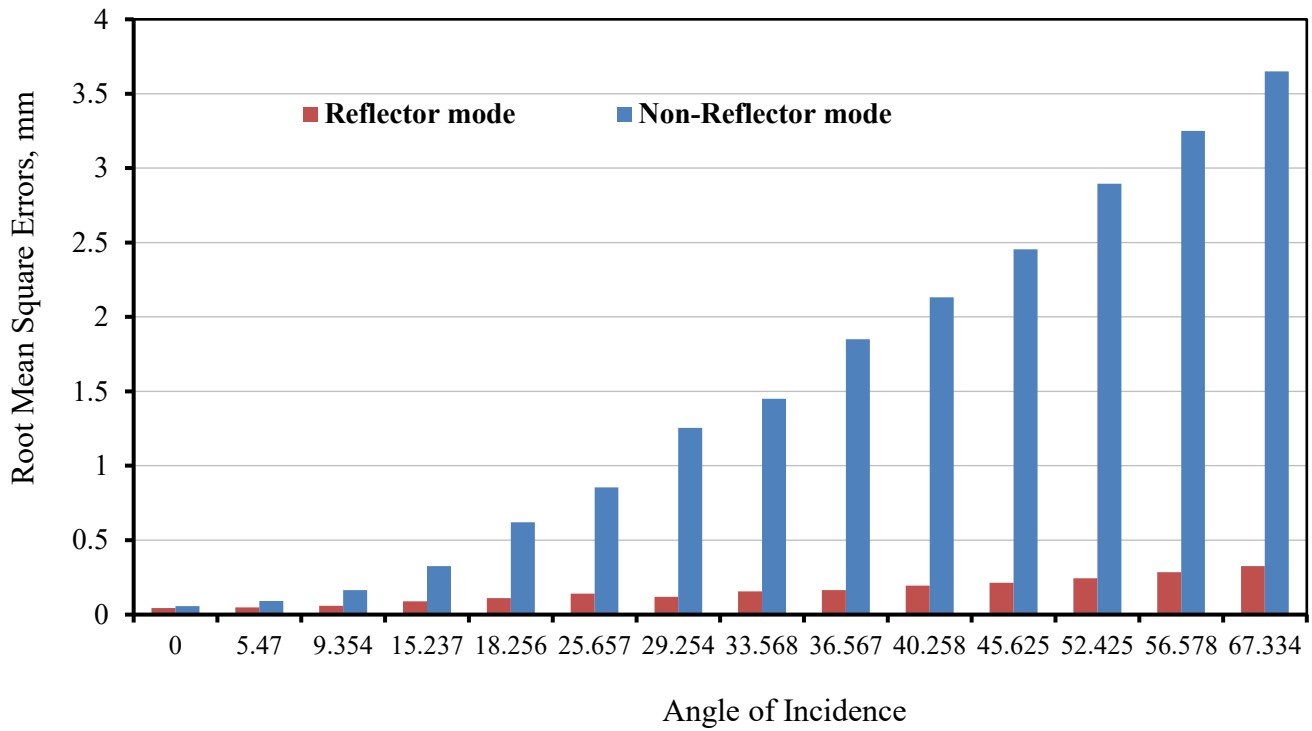


Fig. 11. The accuracy of the reflector and non-reflector observations by Leica TS16P1R500 with different angle of incidence

The outcome of practical study for figures 10 and 11 illustrates that:

- The error in measuring distance increases as the angle of incidence in the target increases, particularly in the absence of a reflector.
- The distance error at a specific angle of inclination in the case of reflector-less surveying is greater than that of distance error in the case of prism surveying at the same angle of inclination.
- Once the angle of incidence reaches thirty-five degrees from the normal, any observed data becomes unreliable, and cannot possibly match the manufacturer's specification in the reflector-less case.
- It is obvious that the error decreases drastically with the angle of incidence approaching zero. In addition, it is advised that the horizontal angle of incidence should be in the range (-36 to +36) from the square.

4.4.1. Nonlinear Regression Modeling of Incidence Angle Effects on EDM

The second-order mathematical model was constructed to study the effect of incidence angle on the distance measurement accuracy when using the Leica TS16P1R500 total station in two modes, namely, with and without prism. The quadratic regression models were used in describing the non-linear behavior of the errors in the distance measurement in relation to the incidence angle presented in figure 12. The equations for the regressions are presented below:

396 Prism Measurements

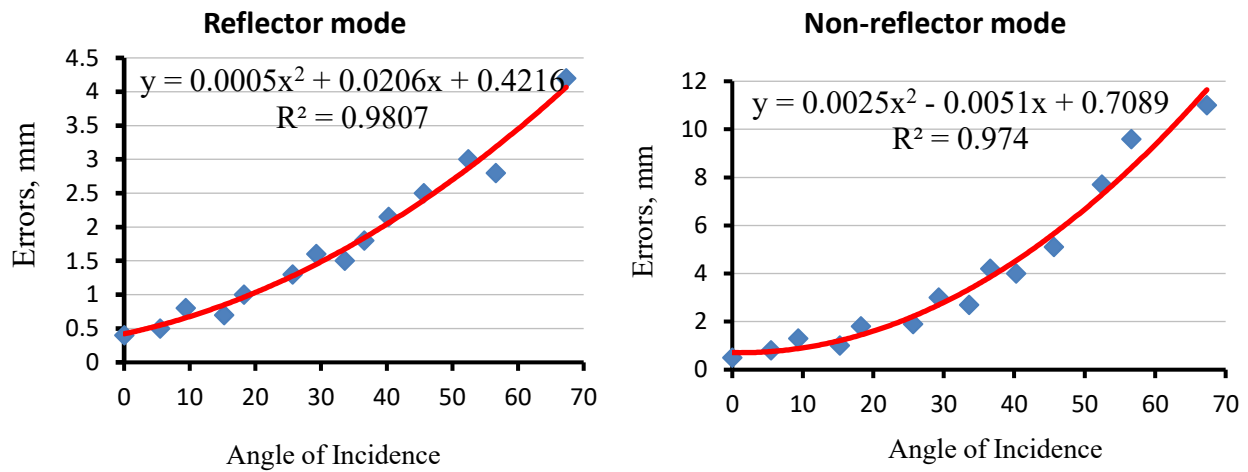
$$397 E_p = 0.4216 + 0.0206 \alpha + 0.0005 \alpha^2, \text{ with } R^2 = 0.9807 \quad (7)$$

398 Reflector-less Measurements

$$399 E_{n-p} = 0.7089 - 0.0051 \alpha + 0.0025 \alpha^2, \text{ with } R^2 = 0.974 \quad (8)$$

400 where:

- 401 • E represents the measured distance error (mm),
- 402 • α denotes the incidence angle ($^\circ$),
- 403 • R^2 coefficient of correlations.



404

405 **Fig. 12** Regression analysis of prism and reflector-less measurement errors versus observation angle of incidence

406 Residual analysis showed that the prism observations have very low and consistent residuals. The residual values varied
 407 from -0.4 to +0.2 millimeters with the average value being 0.005 millimeters. These results indicate high correlation
 408 between the observed and estimated values and suggest the consistency of prism observations irrespective of the changes in
 409 the incidence angle. Low residual values suggest that prism observations are not greatly influenced by the angular effects
 410 since the laser reflection is consistently geometric and coherent.

411 On the other hand, reflector-less measurements showed significantly higher residual variations between -1.50 mm and +2.0
 412 mm with an average residual value of -0.5 mm. This high level of residual variation implies that reflector-less
 413 measurements are much more susceptible to incidence angle variations especially when observing incidences at angular
 414 positions far away from normal incidence. This is due to scattering effects, divergence of light beams, and weakening of
 415 reflected signals observed by the measurement device.

416

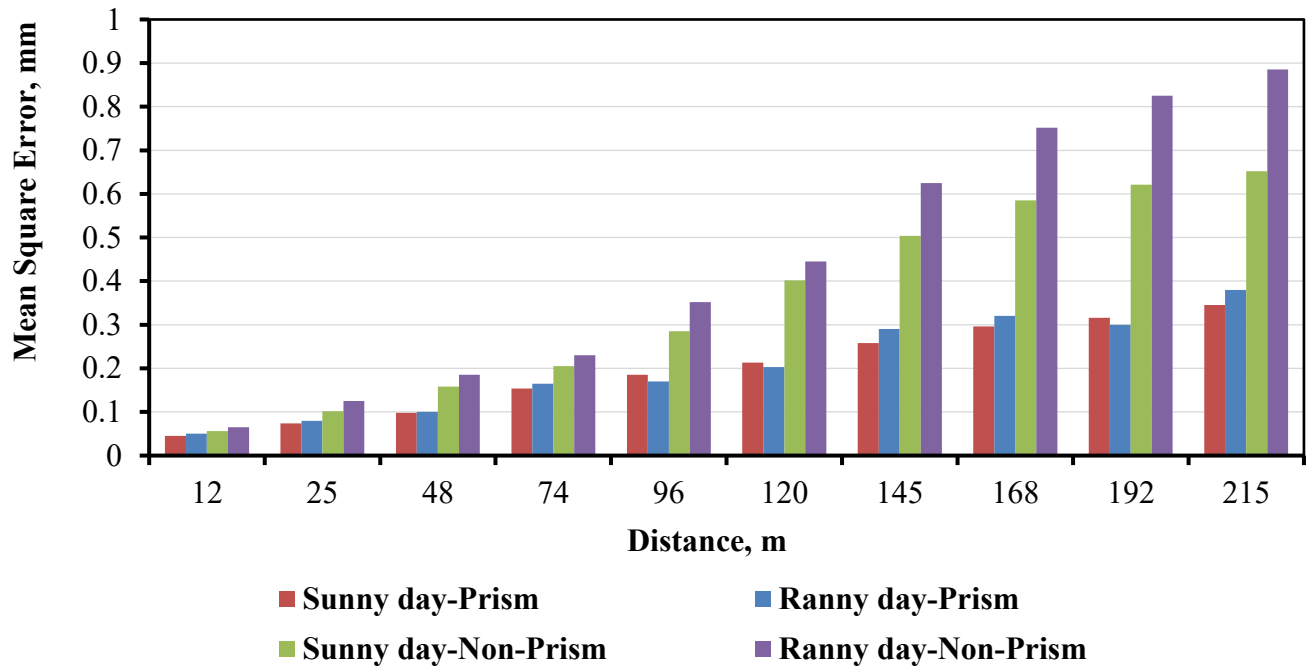
417

418 **4.5. Studying the Effect of Weather Conditions:**

419 The previous static experiments were conducted in sunny weather. In order to test the influence of weather change on
 420 measurement accuracy, an experiment on a rainy day was performed. The distances re-measured using the Leica TS16 P1
 421 R500 total station for two series of measurements in reflective mode with a s circular prism as target and in non-reflective
 422 modes using a white wooden target in a rainy day time in January at 7 degree of temperature. The mean differences values
 423 of distances, which measured using Leica TS16 P1 R500 Total Station in two cases of prism and non-prism with different
 424 weather conditions were presented in table 5 and their Root Mean square errors in figure 13.

425 Table 5 Differences for measured distance in different weather conditions in prismatic and non-prismatic options using
 426 Leica TS16 P1 R500 total station

Distance	Reflector ability		Reflector-less ability	
	Sunny	Rainy	Sunny	Rainy
12	0.4	0.5	0.5	0.5
25	0.5	0.4	0.6	0.8
48	1.0	0.9	0.9	1.1
74	0.7	0.8	0.8	0.9
96	0.7	0.8	0.9	1.1
120	1.0	1.2	1.2	1.6
145	1.4	1.5	1.8	1.9
168	1.6	1.5	2.1	2.4
192	1.5	1.6	2.0	2.3
215	1.6	1.7	2.4	2.8



427

428 Fig. 13. The Root Mean Square Error of the reflector and non-reflector observations with different weather conditions using

429 Leica TS16 P1 R500 total station

Results of table and figure indicated that:

- The effects of atmosphere on the distance calculation using prisms are relatively small and negligible, since the signal reflects from a reliable prism and atmospheric corrections are easily obtained; the error of such measurements will be on the millimeter order of magnitude. Nevertheless, in reflector-less surveys, the signal is subjected not only to atmospheric influences but also to its reflecting properties depending on the surface characteristics. Changes in temperature, humidity, and air turbulences can drastically decrease the accuracy of measurements up to half centimeter level.

- For long ranges exceeding 100 m, the effects of atmosphere on the reflector-less survey results become much stronger in comparison with those for prism-based distance calculation. This happens because of the influence of atmospheric refraction and dependence of signal reflection on surface characteristics.

In contrast to earlier research, which focused on individual parameters in isolation, the current study takes an integrative perspective by analyzing several parameters at once. This helps in generating a realistic scenario, wherein the effects of various parameters work together to affect the outcome. Thus, this study offers an enhanced insight into total station behavior.

4.5.1. Atmospheric Refraction and Beam Propagation Effects:

Measurements of distance made electronically by means of total stations influenced by atmospheric propagation effects because the emitted laser beam travels through a nonhomogeneous medium before returning to the instrument receiver. changes in temperature, humidity, pressure, and air turbulence in the atmosphere could affect the refractive index of air.

Regarding prism-based measurements, the received light signal is reflected from an optical prism, which ensures the reflected signal to be highly accurate and coherent. Hence, the impact of atmospheric interference on the received light signal becomes insignificant, especially at shorter observation ranges. It is because of this phenomenon that the low RMSE value and uniform residual distribution are observed in the case of prism-based measurements. On the other hand, the accuracy of measurements without a reflector appeared much higher sensitivity to atmospheric variations. This can be explained by the fact that, the received signal is determined by diffuse reflection from the surface of the object, thus making it susceptible to changes caused by atmosphere. In wet conditions, the laser beam becomes unstable and partially loses energy.

From the experimental results presented in this investigation indicated that the role of atmospheric interference becomes increasingly important for reflector-less measurement over distances greater than 100 m. This trend is consistent with the outcomes of regression analysis, which showed increasing distance-related errors in the reflector-less configuration relative

458 to those from prisms. In addition, it should be noted that atmospheric interference can lead to changes in the refractive
459 indices of air within the light beam path, resulting in slight deviations of its direction and stability of movement.

460 **4.6. Limitations and Future Research**

461 Some limitations have to be kept in the mind when interpreting the results of the current research. The present study has
462 some limitations that should be considered when interpreting the results. The experiments were conducted using a single
463 Leica TS16P1R500 total station, selected prism and target types, and observation distances ranging from 12 to 215 m.
464 Therefore, the obtained error characteristics and regression relationships should primarily be considered within the
465 investigated instrument, target characteristics, environmental conditions, and distance range.

466 Future research should extend the experimental investigation to other total station models and manufacturers, longer
467 observation distances, and a wider range of surface materials, colors, textures, and reflectance properties. In addition,
468 systematic measurements under different atmospheric conditions, including temperature, humidity, pressure, wind, and
469 precipitation, would provide a more comprehensive assessment of EDM performance.

470 Further studies could also develop multivariable regression or machine-learning models that simultaneously consider
471 observation distance, incidence angle, target characteristics, and atmospheric parameters. Such models could support the
472 prediction of EDM measurement errors and improve the reliability of reflector-less measurements in engineering surveying
473 and deformation-monitoring applications.

474 **Conclusions:**

475 This study provides a thorough analysis of the accuracy of measuring distances in the use of the Leica TS16 P1 R500 total
476 station both in prism and non-prism conditions. The results show that the accuracy of measurement depends on the
477 combined effects of geometry, environment, and surface parameters, and not necessarily the instrument parameters alone.
478 Results from regression analysis indicated that prism readings showed consistency with the specified accuracy from the
479 manufacturer across the range of interest, while the reflector-less method displayed increasing discrepancies, especially
480 when atmospheric and geometrical conditions were poor, and incidence angles were more than 30° and ranges greater than
481 100 m.

482 On the basis of the results of the research carried out, the authors have found that:

- 483 - For surveys requiring high accuracy, it is essential to utilize circular prisms rather than mini prism or 360° prisms. The
484 error associated with the position of the 360° prism can reach several millimeters, as shown by various experiments
485 conducted during this study

- 486 - The standard deviation of the readings of the Leica TS16 P1 R500 total station at a distance of up to 200 m using high
487 precision GPH1P circular prism does not exceed 0.3 mm, corrections for the measured length are consistent and can
488 be taken into account during individual calibration;
- 489 - The standard deviation of measured distances for the range finders TS16 P1 R500 total station in reflector-less mode is
490 no more than 0.5mm and the deviations between measured values and their referenced can reach 2.5 mm.
- 491 - The accuracy of distance measurement using the reflector-less total station option and the prismatic option converges at
492 short distances (up to 100 m); beyond that distance, the accuracy of the prismatic option is better than the reflective-
493 less option.
- 494 - As the incline angle of the reflecting surface increases, the error in distance measurement using the reflector-less total
495 station increases as well, getting the highest measurement accuracy achieved only when the target has an incline angle
496 equal to 0
- 497 - Out of all the surface targets used in the reflector-less total station, the best performing target was the brick and wood
498 target and the least effective was the metal target.
- 499 - The accuracy achieved with a white target is greater than of any other colored surface, whereas the results obtained
500 from a black target show the least amount of accuracy.
- 501 - There is not a significant effect of weather on the precision of surveying with a total station using prisms because the
502 prism is stable and has met standards for applying atmospheric correction.
- 503 - In case of reflector-less measurements, the impact of atmospheric conditions on the quality of measurements is
504 substantial. It is explained by the fact that the reflected signal travels through the atmosphere and reflects from the
505 surface of the target object.

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512 The author report there are no competing interests to declare

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515 **Data Availability Statement:**

516 “The data that support the findings of this study are available from the corresponding author upon
517 reasonable request.”

518 **Conflict of Interest:**

519 The author declares that there is no conflict of interest regarding the publication of this paper.

520 **Ethical Approval**

521 This study does not involve human participants or animals, and therefore ethical approval was not required.

522 **Author contribution:**

523 Sobhy Abdel Monam Younes: Conceptualization, literature review, methodology, experimental design, field
524 measurements, data analysis, statistical and regression analysis, preparation of tables and figures, interpretation of results,
525 manuscript writing, revision, and supervision.

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577 **Figure Legends:**

578 **Figure 1.** Leica TS16P1R500 high-precision total station used for the experimental EDM measurements.

579 **Figure 2.** Target types used with the Leica TS16P1R500 total station: (a) Gph1p high-precision circular prism, (b) PE640b
580 64 mm mini prism, (c) Ads360-13 Apt3 360° surveying prism, and (d) reflector sheet mounted on the specially designed
581 supporting base.

582 **Figure 3.** Study area and calibrated baseline used for the experimental distance measurements.

583 **Figure 4.** Comparison of measured distances and reference distances for the Gph1p, PE640b, and Ads360-13 Apt3 prisms
584 using the Leica TS16P1R500 in reflective mode.

585 **Figure 5.** Mean square errors of distance measurements obtained with the Gph1p, PE640b, and Ads360-13 Apt3 prisms at
586 different observation distances.

587 **Figure 6.** Comparison of distance measurement errors obtained using reflector and reflector-less modes relative to the
588 reference distances.

589 **Figure 7.** Comparison of mean square errors of Leica TS16P1R500 distance measurements obtained in reflector and
590 reflector-less modes.

591 **Figure 8.** Linear regression models describing the relationship between EDM measurement error and observation distance
592 for prism and reflector-less measurements.

593 **Figure 9.** Residual distributions of the prism and reflector-less regression models as a function of observation distance.

594 **Figure 10.** Distance measurement errors obtained with prism and reflector-less modes at different angles of incidence.

595 **Figure 11.** Mean square errors of prism and reflector-less distance measurements for different angles of incidence.

596 **Figure 12.** Quadratic regression models describing the relationship between EDM measurement error and incidence angle
597 for prism and reflector-less observations.

598 **Figure 13.** Mean square errors of reflector and reflector-less observations under sunny and rainy weather conditions at
599 different observation distances.

600 **Table Legends:**

601 **Table 1.** Technical specifications of the Leica TS16P1R500 total station, including angle measurement accuracy, prism and
602 non-prism distance ranges and accuracies, target acquisition characteristics, environmental specifications, battery life, data
603 storage, and field software.

604 **Table 2.** Comparison of measured distances using the Gph1p high-precision circular prism, PE640b 64 mm mini prism, and
605 Ads360-13 Apt3 360° surveying prism at observation distances from 12 to 215 m. Differences from the calibrated reference
606 values are presented together with their mean, minimum, maximum, and corresponding $\Delta/2$ values.

607 **Table 3.** Mean values and mean square errors of reflector-less distance measurements obtained from different target surface
608 materials, including gypsum board, wood, plastic, brick, ceramic, concrete, and metal, at observation distances of 12 and 26
609 m.

610 **Table 4.** Mean square errors of reflector-less distance measurements obtained from wooden targets with different surface
611 colors at observation distances of 12 and 26 m.

612 **Table 5.** Differences between measured and reference distances under sunny and rainy weather conditions using prism and
613 reflector-less measurement modes at observation distances from 12 to 215 m.

614