Important methods measurements to exam the accuracy and reliability of reflector-less total station measurements

Shireen Ibrahim Mohammed
Dams and Water Resource Department, College of engineer/ University of Anbar, Anbar, Iraq.
Email : shireenmohammed@uoanbar.edu.iq

Abstract. Inaccessible points are difficult to measure because the prism cannot be position in these points, so reflector-less total station has solved this problem and these points can be measured easily. But the vital question is, if these measurements are accurate and reliable. This research has carried out to identify the vital methods measurements that have to be done to identify the reliability and the exact accuracy of the reflector-less measurements. Results are not general for all total station types because each instrument has its own specifications, and the continues use of the instrument (old used instruments) could affect the accuracy of measurements. In the third world countries or in specific in our cities, old version surveying instruments are still used in most projects. In some projects specially in high accuracy projects (such as bridges monitoring by using total station), it is important to know the exact distance that errors are going to be introduced by using reflector less total station (the distance between the target and the instrument). By identifying the limitations, the errors can be avoided, and the required accuracy can be obtained. In this research many observations in different locations are carried out in two situations, the first one by using prism and the second one by using reflector-less mode to compare between them. This study has identified many aspects include: the effects of beam divergence and the incidence angle on the accuracy and reliability of the measurements. In addition, the limitation of the reflector-less technology when the high accuracy is required. Furthermore, it has suggested the solution to this problem. In this research methods measurements to exam the reliability and the exact accuracy of the reflector-less measurements have been identified for total station Topcon ES-103, and these methods could be used to any type of total station before start in any high accuracy project. When the reflector-less measurements limitations are identified, the errors could be avoided.

Keywords. Reflector-less Measurements, Total station, Angle of Incidence, Beam Divergence, Accuracy and Reliability …

1. Introduction
In order to achieve the accurate results that meet the specifications of the project such as engineering surveys and monitoring measurements, the knowledge of the accuracy and the reliability of the surveying instruments is crucial. Many projects such as structures deformations are needed to be measured accurately in order to determine the structure's safety and stability. Ground surveying is an accuracy method that can be used to monitor the structural deformation [1]. The precision and the accuracy of the measurements depend on the accuracy of the applied surveying technique. One of the advanced available surveying techniques is the reflector-less (prism-less) total station. Reflector less total stations are used in many applications due to their highly accurate and fast measurements in an automated measuring process[1]. This technique does not require a prism and can simply reflect off almost anything. The main advantage of the reflector-less total station is the ability to measure inaccessible points [2]. In other words, the use of reflector less total station in projects allows to work
without special reflectors (prisms) and its possible to measure without prisms and just measure to necessary points. The accuracy of this technique depends on many factors include: the signal power that is reflected from the surface, the returning signal intensity, distance from total station to the target, the angle of inclination of the reflected signal, and the angle of incidence[3].

In some cases of observations, measurements give less accuracy than expected and the points positions determinations by using reflector less total station is subject to have some errors due to several sources of errors that affect the accuracy of measurements. Most surveying measurements can be checked for errors, while in reflector-less measurements are hard to check[2]. So, in order to rely upon such measurements, especially when high accuracy results are required, it is important to identify the main parameters that can affect the accuracy of reflector-less total station observations and identify the methods to detect this reliability.

Reflector-less total station or prism-less total station means applying measurements without using the prism, which means that the signals are reflects from the target itself. These measurements are useful for the points that are inaccessible. The inaccessible points include underground mining points, crowded areas, high points in the buildings…etc. Such points cannot be checked for errors, so it is very important to be aware about the reliability of this technique especially with high accuracy surveying works. Although measurements always have errors[4], they can be accurate if these errors are acceptable. In surveying errors include random errors, gross errors, and systematic errors. Gross errors are non-cumulative errors and can be small or big and they could be found by checking the measurements, while systematic errors are cumulative errors, and they could be small or big. Both gross and systematic errors can be corrected mathematically while random errors are difficult to correct or minimize because they are non-cumulative small errors and part of measurements[5].

As far as reflector-less measurement errors are concerned, reflector-less is not prone to random or gross errors, and systematic errors is difficult to occur[6]. The problem with reflector-less is with the signal size when the observations are in a long distance from the target because it is difficult to know where the signal is reflected from[7]. Beam divergence is the main problem that affect the accuracy of the reflector-less measurement. Because when the target-instrument distance increase, the spot laser increase, and the incident angle with the surface increase as well which causes unreliable accuracy measurements[8]. In addition, according to[7], laser beam which is scattering back from the target may distortion and cause errors in distance measurements. The ideal situation that causes no errors in the reflector-less measurements is when the instrument setup at a perpendicular angle from the target, but this is impossible for all targets locations.

The aim of this research is to identify the suitable methods measurements in order to investigate the reflector-less total station reliability and limitations, and to identify the main factors that can affect the accuracy of measurements. In addition, to offer some recommendations to avoid these limitations and use this technique in high accuracy project.

2. Total Station

Total station is an electronic surveying instrument, it is a combination of an electronic distance meter (EDM) with an electronic theodolite[9]. A theodolite measures the angles in two directions by reading two circle scales, the horizontal circular scale which gives the tilting angle between zero direction and the line of sight(horizontal plane), and vertical circular scale that gives the tilting angle between the zenith and the line of sight (vertical plane)[10]. The electronic distance meter (EDM) measures the distance (slope distance) by using the laser, that reflect back from the prism or from the target itself[7]. There are two types of scanners to measure signals, the first one is ‘time of flight’ (TOF) This type of scanner emits a laser energy light pulse and then measure the travel time of the pulse (from the instrument to the target and back again to the instrument) to measure the distance. Or according to[11,12,13] time-of-flight sends a laser pulse to the target and use the time difference between the emitted and received pulses to determine the range. The advantage of this type includes it is suitable for scanning large structures such as geographic features and buildings because the capability of it to operate over long distance and long range[14]. While the disadvantage of this type is that, the accuracy may lose
when the signal hits the edges of an object. This is because the reflected information is from two different locations, so the coordinates will be calculated based on an average and will put the point in wrong position [12]. The second one of scanner type is called 'phase shift'. This type uses the laser energy light's beam to determine the distance. The distance is accurately calculated by measuring the phase shifts in the waves of infrared light [15]. These waves are in varying lengths which are transmitted to the object and reflect back to the instrument. So, by measuring change of phase of the laser, the distance is calculated. In other words, and as demonstrated in [13], phase shift uses the difference in phase between the emitted and received backscattered signal to determine the range. The main difference between the two types is the phase shift has narrow beam which makes it more accurate but has small rang, while time of flight has greater distance than the phase shift but has wide beam signal, which makes it less accurate [6,7].

The Coordinates (X,Y,Z) for any unknown point can be determined by using total station as long as the line of sight can be established [10]. This is done by setting up total station over a known coordinate point, and line of sight observation is established to the unknown point. After that distance and angle are measured to this point, then total station calculates the coordinates by using triangulation and trigonometry [10].

Total station has many advantages includes collect information very quick in one set-up location, more than one surveys can be performed, easy to use, construction site layout information can be collected quickly and efficiently, the data can be downloaded quickly into CAD which is time consuming, and it is use in many more different applications. While the disadvantages include sometime the accuracy of vertical elevation is not as accurate when using the other conventional survey (road technique and level), the obtaining horizontal coordinates in total station are based on a rectangular grid system and in large projects such as large buildings and highways these coordinates must be transformed to geographic coordinates [6]. In this paper important methods are applied to exam when the errors are introduced in total station measurements in order to avoid the causes of these errors before start with any high accuracy project.

### 2.1. Reflector Less Total-Station

As mentioned previously, EDM measures the distance (slope distance) by using the laser that reflects pack from the prism or from the target itself. When the laser is reflecting back from the target itself, the measurement is called reflector less measurements or prism less measurements. Reflector less mode is used for inaccessible points such us light pole top, busy highway, building corner etc. This type of measurement has many advantages: it's useful for inaccessible location, safe to use, no need for person for reflector, saving labour costs, and time consuming. The accuracy of these measurements depends on the instrument-target distance, because as long as the distance is short, the accuracy is good [6,16]. It is vital to the user to be aware about their limitations to use these measurements correctly. The main limitation of the reflector-less measurements are the errors that caused by angle of incidence and beam divergence. Beam divergence is the main reason of the reflector-less measurement errors. In order to measure the target accurately, the target should be within a certain angle relative to the total station itself. In addition, long distance affects the measurement, when the target-instrument distance become too long, the angle to the surface may increase which causes that the measurement beam doesn’t reflect from the target itself.

### 3. Methodology and Result

There are many types of total station and each one has its own manufactures, accuracy, specifications and range of reflector-less mode. Total station Topcon ES-103 has been used in this study, and table (1) shows the instrument and some of its specifications.
Table 1. Total station Topcon Es-103 specifications [17]

| Specifications                  | Value                     |
|--------------------------------|---------------------------|
| Angular accuracy               | 3"                        |
| Distance accuracy –prism        | (2+2ppm *D)mm             |
| Distance accuracy-reflector-less| (3+2ppm* D)mm             |
| Laser-pointer                   | Coaxial red laser using EDM beam |
| Guide light                     | Green LED(524nm) and Red LED (626nm), Operating range:1.3 to 150m(4.3 to 490ft) |

The investigation of the reflector-less instrument's accuracy has divided into two main parts: Beam divergence and angle of incidence effects. Beam divergence effects includes measuring small size target from different distances, measurements to an internal angle, and measurements to an external angle. While angle of incidence effects includes measurements to vertical target and measuring a target from different incidence's angles. Before starting the measurements, the confirmation of the instrument accuracy specifications had established for the reflector-less and for the prism measurements.

This confirmation has done by measuring a distance to a white target in perpendicular angle, and repeat the measurements from four different distances to the same target by using reflector-less signal and prism. The measurements were repeated several times at zero incidence angle in order to be checked for deviation. The four distances from the whit target to the total station were 10m, 40m, 80m,100m.

Table 2. The Different Distances Measurements of Reflector- less Total Station and Prism

| Distance (m) | error | Reflecter-less | Mean | Reflecter-less | Mean | Std.Dev |
|--------------|-------|----------------|------|----------------|------|---------|
|              |       | prism          |      | prism          |      |         |
| 10           | 1     | 0              | 0.6  | 0.4            | 0.5  | 0.5     |
| 40           | 1     | 1              | 0.4  | 0.4            | 0.5  | 0.5     |
| 80           | 2     | 1              | 1    | 0.6            | 0.6  | 0.5     |
| 100          | 1     | 0              | 0.6  | 0.6            | 0.5  | 0.5     |
Table (2) illustrates the different distances measurements by using the reflector-less signal and the prism of total station. Although there were different ranges and errors in the measurement but all these lie is very small range. This rang that lies within the manufacturers specifications. After the confirmation of the total station’s specifications has done, many tests have been carried out to test the accuracy of the reflector–less signal in different situations.

3.1. Beam divergence's effect

3.1.1. Small size target Measurements
This test has carried out in order to investigate the distance that the small object could be measured accurately before the beam diverges give any inaccurate results. Two targets with two different diameter size were used, for each target the horizontal distance has measured two times, the first time by using a prism for checking and the second time by reflector-less sign. The measurements have started by placing the total station at right angle to the target with small range distance and zero incidence angle to eliminate the non-normal measurements errors, and then the distance from the targets were increased gradually. The diameters of the targets were ten and twenty millimetres, the two targets were painted by white colour in order to avoid the reflective effects [18].The distances have measured but as the distance increased from the target, the beam divergence width increased as well, and that is occurred because the reflected signal had returned from the background not from the target. So, it is very important to know the distance that the measurement could be measured accurately to the target before the beam divergence is going to be increased.

Fig(1) shows the relationship between the target- instrument distance and the measurement’s errors to the target .It illustrates that there was difficult to observe the small size object accurately, the small target with ten diameters wasn’t read accurately and the error was increased as the distance increased between the instrument and the target, while the target with twenty millimetres was read accurately until nearly twenty nine meters but after that as the distance increased there was error in the measurement but was very small and less than the error from the other target. Clearly, big size target can be measured accurately for longer distance.

![Fig 1. Beam Divergence Errors To Small Target](image)

3.1.2. Corners (internal and external corners) measurements
This test has done in order to identify the measurement's errors that caused from corners observations from different distances. Again, the problem with corners measurements is with the beam divergence. As mentioned previously, the beam width increased as the distance from the target increased. When the distance increases from the corner, the width of beam increases, and the range between the longest and shortest signals that returned to the total station increases as well. So, the measurements to the corners (internal and external) were done by measuring each corner from different distances starting with close distance and then it was increased far away from the corners starting from 10 meter and then increased ten m each time (10m, 20m, 30m, …….80m). Fig (2) shows that for the internal corner that the error increases as the distance increases, after nearly thirty meters the measurements become inaccurate and unreliable, and These errors were because of the beam divergence had produced measurements from the adjoining walls not from the internal corner itself. While the external corner there was error in the measurement but was expectable until nearly seventy meters and then the error increased. The error has introduced due to the divergence (the size of returned signals become bigger as the distance increased) and this causes errors in the measurements.

![Fig 2. Errors In Internal and External Measurements](image)

### 3.2. Angle Of Incidence Measurements

#### 3.2.1. Measurements to vertical surface

As measuring the inaccessible points is the main use of the reflector-less sigh, this test is vital. This test has carried out in order to measure the points that are in height position and can't be reached to put the prism in. In this test tall wall was chosen with targets on it. These targets in this trial were in high that can be reached for checking in order to compare between the measurements. So targets were chosen and were measured twice, first time with prism and second time with reflector-less sign. Total station was set up at close distance from the wall in order to avoid any errors caused from the long distance, and five points on the wall were chosen to measure as shown in Fig (3). While Fig (4) shows that the errors with reflector-less measurements increase as the incidence angle increases, and the reliability decreases as the incidence angle increases.
Fig 3. Measurements to a wall

Fig 4. Errors of measurements to vertical surface

Table (3) shows the incidence angles with the errors that shown in the graph, the errors were within the specification of the instrument except the last one has big and an acceptable error that has caused by incidence angle which was large.

| Position | Horizontal distance (m) | Vertical distance (mm) | Slope distance (m) | Angle of incidence (°) | Reflector less error (mm) |
|----------|-------------------------|------------------------|--------------------|------------------------|--------------------------|
| 1        | 3.60                    | 0.056                  | 3.64               | 00 53                  | 1                        |
| 2        | 3.60                    | 0.760                  | 3.68               | 11 55                  | 3                        |
| 3        | 3.60                    | 1.269                  | 3.82               | 19 25                  | 2                        |
| 4        | 3.60                    | 2.068                  | 4.15               | 29 52                  | 3                        |
| 5        | 3.60                    | 3.295                  | 4.88               | 42 28                  | 8                        |

3.2.2. Measurements of a Target That is Not In a Right Angle Position From The Instrument
This test is very important to test the reflector–less measurement of a target that is not in a right-angle position from the instrument.
In this test five targets were used with five meters interval distance between them, and the target measured twice with prism and with reflector-less mode from two distances, the first distance was 20 meters and the second was 10 meters from two different positions as shown below in Fig (5).

Fig 5. Measurements to targets in different incidence angles
Fig (6a, b) show that the errors increase as the angle increases to nearly more than 35 degrees. So, the reason of these errors is when the incidence angle increases, the distance increases as well, which caused errors in the measurements.

![Graph]

**Fig 6a.** Incidence angles when the instrument-target distance 10m

![Graph]

**Fig 6b.** Incidence angles when the instrument-target distance 20m

4. **Conclusion**
This research has carried out to identify the important methods measurements in order to investigate the reflector-less total station reliability, accuracy, and limitations, and offer suggestions to use it in projects that are required high accuracy.

It has been proved that with reflector-less measurement, the errors are introduced when the distance increases between the target and the instrument, and that is because of the beam divergence which affects the accuracy of the observations. For corners, the internal corner measurements become inaccurate when the distance is increased to more than thirty meters, while for external corner the measurements become inaccurate when the distance is more than seventy meters between the target and the instrument. In addition, it has been proved that when the incidence angle increases, the errors increase. For two observations (measurement to vertical surface and measurements to targets in different incidence angles), it has been indicated that when the angle of incidence reaches to nearly more than thirty-five degrees, the measurements become unreliable and inaccurate. [6] suggested many solutions that may solve these problems depending on the indirect measurements. Firstly, two intersection walls can be measured to avoid corner measurements errors. Secondly, to avoid any objects interference,' max range' and' min rang' instrument can be used. thirdly, the edge position can be determined by measuring the
distance to the target’s centre and use offset (angle/distance offset). Finally, using face left and face right measurements in order to omit the slop effect which caused by an oblique angle. These results are not general for all total station types, each instrument has its own specifications and own limitations depending on many reasons such as the continues use of the instrument and its type, which could affect the accuracy of measurements. So, these methods measurements of reflectorless total station can be used before starting with the high accuracy work and to be aware about limitations and the right distance that should be taken before the errors introduce and affect the accuracy.

References
[1] Zeidan Z.M, Beshar. A.A, Sameh. S.M, 2015. Precision Comparison and Analysis of Reflector-less Total Station Observations. Mansoura Engineering Journal, (MEJ), Vol. 40, Issue 4: [the 8th C: 68 International Engineering Conference
[2] Beshr A A “Development and innovation of technologies for deformation monitoring of engineering structures using highly accurate modern surveying techniques and instruments, Ph.D. thesis, Siberian State Academy of geodesy, Novosibirsk, Russia.
[3] Beshr.A.A, Abo Elnaga .I.M, 2011. Investigating the accuracy of digital levels and reflectorless total stations for purposes of geodetic engineering. Alexandria Engineering Journal, 50,399-405.
[4] Parkhomenko D V and Predtechenskaya E A. 2020.Methodology for conducting and analyzing land surveying examinations. IOP Con.Series:Earth and Environmental Science 579,doi:10.1088/1755-1315/579/1/012112.
[5] Xu P, Shi Y, Peng J, Liu J and Shi Ch. 2013. Adjustment of geodetic measurements with mixed multiplicative and additive random errors. Journal Geodesy, Springer, 87, pages629–643.
[6] Coaker L.2009, Reflector-less Total Station Measurements and their Accuracy, Precision and Reliability. University of Southern Queensland- Faculty of Engineering and Surveying.
[7] Zamecnikova M, Neuner H, Pegritz S and Sonnleitner R. 2015,Investigation on the influence of the incidence angle on the reflectorless distance measurement of a terrestrial laser scanner, Journal of geodesy, cartography and cadastre.pag37-44
https://www.researchgate.net/profile/Ersilia_Oniga/publication/303688367_Testing_a_new_method_of_digital_images_acquisition_in_the_process_of_3D_reconstruction_of_an_object/links/574d9c8a08ae82d2c6bde22c/Testing-a-new-method-of-digital-images-acquisition-in-the-process-of-3D-reconstruction-of-an-object.pdf#page=37
[8] Leica Geosystem.2005, Reflector less EDM – Laser Class System 1200, Newsletter-No. 17. Switzerland.
[9] Ghekole S.2014. Surveying with GPS, Total station and Terrestrial Laser Scanner, a Comparative Study. Royal Institute of Technology.
[10] Eriksson M.2014, Accuracy and Precision Analysis of Total station Measurements. KTH Royal Institute of Technology. Department of Urban Planning and Environment, Division of Geodesy and Geoinformatics.
[11] Stanley T.2013,Assessment of the FARO Laser Scanner Focus3D for Forest Inventory, [dissertation],University of Southern Queensland Faculty of Health,Engineering and Sciences.
[12] Newham G, Armstrong J, Muir J, Goodwin N, Culvenor D, Pushel P, Nystrom M, Johansen K, and Tindall D.2011. Evaluation of Terrestrial Laser Scanners for Measuring Vegetation Structure. CSIRO Australia.
[13] Puente I, Gonzalez J.H, Martinez S.J, Arias P. 2013. Review of mobile mapping and surveying technologies; Measurement 46, 2127-2145.
[14] Cote J, Widlowski J, Fournier R and Verstraete M.2009, The structural and radiative consistency of three-dimensional tree reconstructions from terrestrial lidar; Remote Sensing of Environment, 113 (5), pp. 1067—1081.
[15] Abellan A, Oppikofer Th, Jaboyedoff M, Rosser N.J, Lim M and Matthew J. 2014. Terrestrial laser scanning of rock slop instabilities. Earth surface processes and landforms, Vol.39, Issue 1, pag 80-97. https://doi.org/10.1002/esp.3493

[16] Lichti D.D, Lamppard J. 2013, Reflectorless total station self-calibration, Taylor & francis, Vol.40, pag 244-259.

[17] ES Series -Topcon Corporation manual. 2013, www.Topcon.co.jp.

[18] Jana M, Katerina V and Lenka V. 2009. Testing of the accuracy of Leica TCRP 1201 total stations, Topcon GPT-7001 and Topcon-8203M. VSB-TU, Ostrava.