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Contents

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An investigation into the Accuracy of Distance Measurements to an object with the Pulse (Non-Prism) Total Station

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Abstract

In order to achieve the results that meet the specifications of a given project, like engineering surveys (e. g., Surveying of Buildings) , the knowledge of the reliability and accuracy of the surveying equipment is inevitable. The reflectorless total stations are used nowadays for several applications in civil engineering work due to their highly accurate , easy and fast measurements in an automated measuring process.

The present paper investigates the accuracy and limits for prismless instrument Total Station especially in relation to observations with large (horizontal and/or vertical) angle of incidence to the reflecting surface , its colours and types, and beam divergence of the measuring signal. This study has been carried out with various surveying field tests by prism and prismless modes, using the pulse (non-prism) TOPCON GPT-2006 Total Station to evaluate the limitations and accuracy of this instrument in surveying the buildings (distance measurements).

The current study has confirmed that while observations at right angles to an object (building) are generally well within manufacturer specifications ($\sigma=\pm10$ mm), observations to surfaces of a building from a position that is not at right angles to the surface of the building (signal beam) can introduce errors.

Also , this study suggests that the angle of incidence of the measuring signal to the building points (external and internal corners and wall surface points) has a large influence on the accuracy of that measurement.

It is recommended to use horizontal angle of incidence for measuring the detail survey points between (-36 to + 36) degrees from the normal. Also, in case of measurements to a vertical surface, the maximum measured vertical angles of incidence was about forty degrees when using prismatic observations and fifty degrees for reflector less measurements. Some surveying techniques and recommendations are suggested to overcome these problems. Moreover, a good understanding of the non-prism instrument is required to get the required accuracy of the project.

When using other total station equipment, the results of the current study can be used as a general guide only. The results of the current practical field experiments, computations and analysis of these tests using various calculations and least squares theory and computer programs (Excel and AutoCAD 2010) are also presented in digital and/or graphical forms.

Key Words : Reflectorless Total Station, Accuracy Investigations, Surveying of Buildings, Angle of incidence, Reflecting Surfaces, Colours, Types of materials, Beam Divergence, Least squares Theory.

1. Introduction

Advances in computer science have had a remarkable impact on all aspects of modern technology. The effects on the data gathering , processing, storing and plotting of the field surveying data have been significant. Survey data can now be collected quickly, efficiently and accurately using the modern computerized surveying equipment (e.g., Total Station).

At present, a variety of total stations are available that can take measurements to a prism and in prismless modes using the phase shift or pulsed methods (Kavanagh et al (1), Uren et al (2). The basic difference between electronic total station and reflectorless total station is that reflectorless total station may be used without a retroprism.

There are two types of measuring signals, ' phase shift' and 'time of flight' (TOF) also known 'pulse'. Phase shift is considered the most accurate and has narrow beam but has the disadvantage of a small range. TOF conversely, has a greater distance but a wider signal, resulting in a reduction of accuracy (Kavanagh et al (1) and Key et al (3). Only a small amount of energy is required to measure a distance to a prism using this technology. The TOF 'time of flight' technology measures the distance by directly converting the time taken for the laser signal (Light) Amplification by Simulated Emission of Radiation to return to the instrument from the prism, while phase shift uses a set of different wavelengths to compute the distance. (Key et al 3).

A recent advancement in total station technology is the reflectorless measuring technique. Manufacturers refer to this technology as "reflectorless", "prismless" or "direct reflex". The range, accuracy and other specifications may vary slightly, but all sufficient for use on the job site (e.g. civil engineering work).

At first the technology was limited by range and measuring beam width issues, but today most of these limitations have been overcome. Reflectorless range has been extended to up to 2000 m. Accuracy of Reflectorless total station are as good as ± (1 mm + 1ppm) However, for ranges of several hundred metres, it is difficult to accurately point the instrument at its target and beam divergence can become a problem (Hahn (4).

The electronic total station has been used for surveying the engineering work (e.g., production of the engineering plan) (ALI et al (5) and (6). For many applications in construction and surveying, it often difficult or inconvenient to place a reflector at one end of the distance to be measured. In reflector less mode , a total station can measure distances without using a reflector (Eiteljorg (7), (8) and (9) .

However, the current project involved the use of the pulse ' time of flight' (TOF) total station (KEY et al (3) to survey the engineering work in order to produce the engineering plan at scale 1/1000 or larger. This total station requires no prism or reflecting tape. The great advantage to using a total station that requires no prism is simple. The survey team does not need to hold a prism, reflecting-tape target or special paper target at the place where each measurement will be made . Moreover, the measurements can be taken by one person (one-person survey operation), saving labour costs and in a reduced time as there is no need to wait whilst the reflector is moved from point-to-point and without long and tedious search of prism. This will lead to increase the productivity and saving field surveying time.

Consequently, a prismless total station makes survey easier and faster rather than the electronic (prism) total station, where it is often difficult or inconvenient to place a reflector vertically at the point to be measured (e.g., a corner of a building), unless using a special reflector (paper reflector or 1mm flat prism) or offset methods. Other applications, where measurements have to be taken to difficult targets that are inaccessible or dangerous to reach.

The reflectorless total station offers new opportunities to surveyors to be used in the field, but it demands knowledge of the technology, not only to gain the benefits of efficiency and speed, but also to ensure that correct measurements are being made.

Reflectorless total station measurement process requires a basic understanding of how these measurements are done. This will lead to the key of successful measurement by the instrument.

From the basic principles of the laws of reflection that the incident ray, the reflected ray emitted from the prismless total station and the normal to the reflection surface at the point of the incidence lies in the same plane and the angle which the incident ray makes with the normal is equal to the angle which the reflected rays makes to the same normal (Ref. (10). Therefore, the problems for using prismless total station are object range, angle of incidence, beam divergence and reflectivity of the surface object (Coaker (11). The accuracy of this instrument depends mainly on these factors. So, it is necessary to investigate the effect of these factors on the accuracy of instrument observations.

In general, the total station can measure and record the horizontal and vertical angles together with slope distance . Then, the three dimensional coordinates (N, E, Z) will be computed by the on board microprocessor (computer) through the use of trigonometrical calculations. Therefore, if the distance is measured incorrectly, then the resultant calculated coordinates will also be wrong. For this reason, distance measurement will represent the essential component of instrument accuracy.

While taking measurements to a flat , perpendicular surface (perpendicular to the prismless signal) will give an accurate results, but this is often in surveying applications (e.g., surveying buildings) either impossible or impracticable. Then, the problem is raised when taking observations to a plane wall surface with angle of incidence greater than zero to left or right side of the instrument.

Moreover, observations to building internal and/or external corners could be suspect, depending

upon how and where the signal is reflected. As the distance from the instrument increases, so does the width of the signal beam. How can we, as surveyors, be confident that the returned signal is from the position at which the instrument is pointed at not from another object that is just off line but closer (or further away) ?
Also, beam divergence can cause errors as the distance from the instrument increases, where the beam signal is emitted in a cone shaped pattern, i.e. it diverges as it goes further away from the emitting source. The reason beam divergence is important is that the surveyor should not assume that a single point of light with no dimensions "pinkpricks" the target at the location of the intersection of the cross hairs Instead, a roughly circular pattern is "splashed" on the surrounding area. Energy is then return from the entire splashed "footprint" (Paiva (12). A number of surveying techniques are developed and recommendation limits for the use of the instrument where high accuracy results are needed.
The current study of the accuracy of the reflector-less instrument can be classified into several parts. Firstly, the accuracy of the instrument has to be proved, both for the prismatic and reflector-less measurements. Secondly, a number of field tests will be carried out to determine how accurate the reflector-less instrument in a number of situations with special application to buildings construction. The results of the present field experiments are summarized and illustrated graphically.

In the current study, Pulse Total Station TOPCON GPT-2006 was used for the accuracy investigations. The specified accuracy of this instrument in Non-prism mode is m.s.e. = ± (10mm) at 3 to 25 m and m.s.e. = ±(5mm + 2ppmxD) at 25m or more, where D is the measured distance in Km. The m.s.e. in prism mode is ± (3mm +2ppmxD) and the horizontal and vertical beam divergence is 10mm of a distance (30-50)m (Ref. (13).
The objectives of the current research are as follows :

(a) Testing the accuracy of the prismless total station TOPCON GPT-2006 by performing various field tests;
(b) An analysis of the accuracy of surveying building surfaces which are covered by different colours (AL-CAPONY) sheets, using reflectorless (pulse) Total Station.

2.Description of experiments

In this section, we will give a presentation of different field surveying tests carried out by means of the prism and prismless Total Station TOPCON GPT-2006 in order to assess the accuracy of the instrument measurements.

2.1. Field Surveying Tests

A number of field surveying tests have been conducted with special application to surveying buildings and to see how the reflector-less results vary. These include :

1. Measurements to a perpendicular white target, to check the accuracy of the reflector-less instrument over a range of distances.
2. Observations with varying angles of incidence to check what accuracy results if the measurements were done to a non-perpendicular target.
3. Direct observations to an external and internal corners of a building to examine where the measured signal is reflected from.
4. Measurements to different materials which are used to cover the building (concrete painted with white and AL-Capony with different colours) in order to prove the accuracy of the reflector-less observations.
5. Measuring to a vertical wall surface with varying vertical angles of incidence to check the effect of vertical angle of incidence when measuring up to a tall vertical wall of a building.

In all the above field tests, The accuracy specifications of each of the total station used in the current study are clearly stated (see Section (1) and the errors obtained from the equipment directly.
The measured distances using prism mode were used as a standard and the observed distances using prismless mode were compared with the standard distance. Moreover, the resultant errors are obtained from the observations of various field survey experiments which are carried out by the author. The results from these experiments will be discussed in Section (3).

2.1.1. Test No. 1 : Perpendicular Accuracy Test

A simple perpendicular measurements test was carried out to prove the accuracy that is stated in the instrument's specifications. The instrument is placed at right angle to the reflector . In this test, any divergence from instrument accuracy specifications can be proved. However, the current test was executed before starting various tests on accuracy.

A simple accuracy test was performed by measuring a distance using a prism mode to a flat paper prism (5x5cm) on a plane wall, and then again using reflector-less mode to a white paper target (A4- Kodak type). This was repeated six times in increasing distance sizes between 10m and 100m to check for deviations using prismatic and reflector-less techniques. The distances from the instrument to wall are 10.008 ,30.162, 49.993, 69.962 and 109.747 m respectively. Moreover, during all measurements, the angles of incidence were of approximately zero.

2.1.2. Test No. 2: Horizontal Angle of Incidence Measurements Test

One of the most important test was the angle of incidence observations, where the reflector-less measurement of an object from a position that is not at right angles to the surface of the object.

However, the situation is common in surveying observations. There are two possible sources of error in this case. Firstly, the optical axis of EDM and theodolite are not matched i.e., the alignment of the measurement signal does not coincide with the alignment of the optical axis measurements. Secondly, the error will increase as distance increases between the instrument and the target due to the size of measuring signal and the effect of beam divergence (Coaker 10) , Paiva (11) and Wunderlich (14).

This test was carried out in the college area , against smooth precast white concrete building. The instrument was set up just 4 m from the plane wall to reduce the error due to the signal divergence which will be increased as distances increases. Measurements were executed and take the average using both face left and face right position and take the average in order to determine any differences caused by alignment with the instrument Coaker (10).

In the current test, a variety of different angles have been selected both to the left and right of square (angle of incidence of zero). A range of observations with angular range of -48.36,-36.25, -28.68, -13.49, 0.0, 5.47, 11.91, 15.07, 25, 29.52 , 33.75, 36.76, 47.43, 67.33 and 73.96 degrees. . This will give an adequate range considering the results of the test. Measurements were taken with reflector (flat plastic prism 4x4 cm) and reflectorless technology.

However, it was noticed during the observations that the range in which the observer can measure the target by the instrument from 36 degrees right to 36 degrees left of square (i.e. the target was positioned on the plane wall in front of the instrument). There are solutions to mitigating this problem, by placing the target nearly normal sighted signal beam or making multiple instrument setups.

Moreover, the measured targets are positioned nearly normal to the sighted signal beam where, the horizontal angles of incidence are more than 36 degree on either side of the perpendicular.

21.3. Test No. 3 : Observations to an external and internal corners of a building

The external corner is a corner that is viewed with walls away from the observer, while the internal corner is one that is viewed with the walls running toward the observer (see Figure 1).

The problem with measuring to corners of a building is the beam 'signal' width and divergence and reflector uncertainty (Coaker (10). AS the distance from the instrument increases so does the beam width, which at corners can cause a range of distances returned to the instrument from one measurement. The claimed divergence of the present Pulse Total Station is 10mm of a distance (30-50) m. However, the beam size will affect the accuracy of the measurement of distance to the corner, whether the distance was measured from the corner itself or to the wall next to the corner.

From the basic principles of how reflector less measurements are done, where, the infrared light is emitted in a cone shaped patterns, i.e. it diverges as it goes further away from the emitting source (Paiva (11).

According to this principle, it can been seen from Figure (1), for Internal corner, the measured distance is too short by distance (d1) and for external corner, the recorded distance is too long by distance (d2). Also, for a plane reflected surface , there is a difference in distance between the edges and centre of the reflected signal beam as shown in Figure (1).

Reflector uncertainty is a situation when the laser beam is reflected off something other than what was supposed to. This could be either in front or behind the desired object. This can only be avoided through care, checks on measurements , and instrument knowledge.

The present test was performed to evaluate the accuracy of observations as the distance increases from the external or internal corner of a building to the instrument , using prismatic and reflector-less modes. Range of distances were chosen from external corners, approximately every 10m but randomly positioned . The distances were ; 9m, 23m, 33m,41m,52m,60m,68mand 78m But, in case of observations to internal corners, the distances are 9m, 16m,23m,41m,49m,57m ,64m and 73m.Both tests were carried out on concrete (painted with white) and both the external and internal are well defined corners ($\sigma = \pm$ 5mm).

Moreover, in these tests, the targets were positioned at approximately perpendicular to the measuring beam signal.

The external corner was measured accurately using a flat paper prism (6x6 cm) which has been stuck to the corner of the wall. Then, from the same position, reflector-less observation was taken with same instrument in non-prism mode. These measurements were repeated twice on face left and face right in order to cancel out any errors involved in the angular measurements of the instrument.

For internal corner observations, one problem was encountered where it is sometimes difficult to set up the target on the corner. Therefore, the flat paper prism (4x4) cm was set up just in front of the corner (offset = 25 mm) and these measurements were corrected by adding 25 mm to the observed EDM distances. Moreover, from the same position , the non-prism observations was conducted. Although, the observed distances did not approach the maximum range of the present TOPCON Total Station.

However, some technique was used to observe two wall shots that intersect the wall, then these two intersecting lines were used to create a corner point using post-processing computer software (Coaker 10) and Paiva (11).

2.1.4. Test No. 4 : Measuring to different materials (e.g., Al –Capony of different colours)

The purpose of this field survey experiment is to make a case study of surveying the buildings which are covered by the new Al-Capony sheets of different colours. This test was performed to see whether different colours surface (Al-Capony) cause any errors in the EDM distances measured using prismatic and reflector-less technology. Recently, the new Al-Capony sheets of different colours are mainly used to cover various types of buildings as a finished surface.

We selected the paved side walk of the University road as the measurements survey test area.

The observations were taken to different colours of the same material, from angles that were close to perpendicular between the signal and the object (target). Also, the vertical angles are approximately zero. Al-Capony flat rectangular targets (4.0x5.5 cm) of different colours were used. These targets have been manufactured by the production company. Also, The colour targets have been set up on the top of the Topcon prism using special piece of fitting with slot and adjusting screw which was designed for mounting (holding) the Al-capony targets at the centre of the reflector. These targets are mounted on a tripod and the instrument was set up over the reference (occupied) starting station No.1 and other observed stations were located on the same straight line (reference direction).

Different distances were used for each measurement. The distances from the instrument to target are 5m, 10m, 15m, 20m, 30m, 40m and 50m respectively. At each distance, different colours of reflectors have been used (e.g., Topcon reflector, white, silver, golden, green, purple ,red, brown, yellow, blue and black) in sequence. These measured distances were recorded. However, the measurements for each distance was repeated twice and the average values were calculated .

However, the accuracy of the reflectorless measurements depends the reflectivity of the targets surveyed. For example, prismless measurements taken to white surfaces are much more efficient than those taken to dark surfaces , masonry and concrete surfaces reflect light well, while trees, bushes, etc., reflect light to lesser degrees; smooth surfaces are also better reflectors, as are dry surfaces compared to wet ones (Kavanagh et al (1). Moreover, the angles of incidence (Horizontal and/or Vertical) of the measurement, atmospheric, visibility conditions can affect the accuracy of the observations. All observations were taken under the same conditions.

In the current experiment, the height of these targets is approximately equal to the height of the instrument in order to reduce the errors arises from the measuring of the vertical angles. This will keep the transmitted and reflecting beam nearly perpendicular to the targets.

2.1.5. TEST No. 5 Observations to a vertical wall surface

The current field trial was executed to check the effect of measuring to a tall wall, using prism and prismless measurements techniques. The application of this test was to measure the heights of any point targeted including inaccessible ones where it is not possible to locate a prism (in reflector less mode) , because, the

ladder is too short, or not able to be used for safety reasons. Also, it is possible to check the effect of the vertical angle of incidence on the measured height.
We use 5m levelling staff with different range of vertical angles of incidence, only one setup was made at close distance to the vertical wall (of about 4 m) . The choice of a close setup to the targets is to reduce the effect of the misalignment between the measuring signal and the cross hairs. In addition, the signal measuring 'dot' (footprint) is small. However, if the same test was executed over a greater distance , the results may not agree with the current test.
The range of vertical angles of incidence was 0 , 10, 20, 30, 40, 45,47 degrees. Face left and face right observations of vertical angles were made to cancel out any errors involved in the angular measurements of the instrument (see Figure (2).
A flat 1mm prism (6x6) cm was used to measure each point. However, there was some difficulty of aligning the cross on the prism with marked cross on the staff and could cause a small amount of error. Therefore, the targets were aligned optically for both measurements modes so as to reduce any possible effects caused by laser pointer misalignment. Moreover, the levelling staff graduations (resolution is 1 mm) were used as a standard height for each measured points. The verticality of the staff which was held against the wall was checked by the builder's spirit level. Also, the maximum measured vertical angles of incidence was about 40 degrees when using prismatic observations and 50 degrees for reflector less measurements. However, it was noticed that in case of executing the prismatic measurements, the measurement was not performed, if the vertical angle is greater than 40 degrees. Also, the measurements was not done if the vertical angle is greater than 50 degrees in case of using reflectorless mode.

3. Analysis of Experimental Results

3.1 Results of Perpendicular Accuracy Test

The results of perpendicular accuracy test are tabulated in Table (1). The mean, standard deviation and range of the observations were calculated. The results from this test show the difference in the EDM distance observed using the Total Station between the prismatic and reflector-less options on the Total Station. However, the observations which are observed not so large, but they can give some indication on the instrument stated accuracy. The standard deviations (accuracy) of the measurements using reflector-less mode are within the instrument claimed specifications ($\sigma = \pm$ 10 mm). There is also a small range between successive measurements only 4mm. It can be concluded that the instrument using reflector-less signal can measure to the specifications, where the object being measured is flat, of reasonable size to reflect the signal and generally normal to the measured signal.

3.2. Results of Horizontal Angle of Incidence Measurements

The angle of incidence test was executed with different angle of incidence and different distances between the instrument and the object (Building). The results of these tests were plotted graphically (see Figure 3).
In the current test, Figure (3) shows that the error increasing as the angle of incidence increases. This graph suggest that the total station has an acceptable observation capabilities where the angle of incidence is less than fifty degrees from square. Moreover, the resultant errors on the right of square would mirror the left side nearly. For measurements both left and right of the normal, accuracy is within tolerance ($\sigma = \pm$ 10mm), while the angle of incidence remains below approximately fifty degrees. According to the line of best fit (polynomial) as plotted by the dashed red line, this tolerance is exceeded when the angle of incidence increases above approximately forty degrees to the right of normal and approximately forty degrees to the left of normal. The results also show that as horizontal angle of incidence increases, so the reliability of non-prism observations decreases rapidly. Other factors such as object material (smoothness of the surface of the object) and colour could also play a part in the reliability of the measurements. The coefficient of colleration (R2) is also shown on the graph (3).
From these results, it is clearly indicates that the error reduces significantly as the angle of incidence approaches zero. Also, it is recommended that the horizontal angle of incidence is between (-36 to +36)
degrees from the square (normal).

3.3 Results of observations to external and internal corners

The final results of the measurements to internal and external corners of the building were plotted graphically as shown in Figures (4) and (5). The results for internal and external corners were different to each other. Moreover, these results show a fairly regular change in the accuracy in general.

From the practical observations of the distances in the current test which are not shown on the Figures (4) and (5), the internal corner always measured short while the external corner always measured long. For the internal corners , the graph (4) illustrates that the error increases as distance from instrument increases . Then, by comparing these errors with the specified tolerance of 10mm or (± 0.2 mm) at plan scale, the measurements are inaccurate beyond 35m as indicated by the error component and the best mean fit function.

For external corner, the error increases as the instrument corner distance increases. the measurements are within the specified tolerance until the distance between the instrument and the corner reaches about 20m. This is pointed out on the graph by the error vector and best mean fit (see Figure (5)). In both cases, the coefficients of correlation (R2) are also shown in Figures (4) and (5).

It can be concluded, the results suggest that the prismless total station are inaccurate from distances greater than 35m for internal corners and 20m for external corners.

The reason that the corner observations were inaccurate was beam divergence. The internal corner measures short and the external long because of first part of the signal returning to the instrument is from where the distance is computed.

For internal corner , as the distance between the instrument and corner increases , the divergence produce observations that are not from the corner itself but from the adjoining walls. But, for external corner, the point of the corner is the nearest to the instrument and will therefore reflect the signal first. Therefore, the returned signal from the corners will introduce the errors due to the beam divergence. . Although, the details of how the prism-less technology is beyond the aim of this research. Further investigations will be required to measure and check the accuracy of round (curved) corners or shapes observations , where it is possible to observe at least three or more points on the curved corner or , then a curve fitting facility can be used to connect these observed points by the desired curved line.

3.4 Results of measuring to different colours surface

In the present test, two cases were analysed Firstly, the errors (deviations) of each measurement (using the observed distance to the prism as a standard to compare other measured distances to colour targets) are calculated. Secondly, the errors of each observation (using the measured distance to a white target as a standard) are computed. In each case, the results of the present test are illustrated graphically in Figures (6) and (7), where the measured horizontal distance has been plotted against the error for different colours targets in reflectorlesss mode. The allowable tolerance as specified by the manufacture of the instrument is ± 10mm at a distance of 30 to 50 m apart from the total station (Ref.12).

In the first case study and from the results of the current test, It is strangely, the closer the instrument was to the targets, the greater error. In our case, the surface of the target is highly reflective and too much data is ing returned to the instrument.

At 5m distance from the instrument, the errors in the distance measurements to white and yellow targets are within the specified tolerance (± 10 mm), all other errors in the distance measurements to all other colour targets exceed this tolerance .

At 10m distance, all errors are acceptable , except that for brown, green, blue and black targets. The reasons for this is that these targets are dark surfaces. The surfaces of these targets have a very low-reflectivity, so they absorb more energy as compared with any other colour targets.

At 15 and 20m distance, all errors are within the specified tolerance and the specified accuracy of the instrument (σ = ±10mm), but the observed distances are too short. At 30m distance, the errors are acceptable but the measured distances are too long.

At 40m distance, all error vectors are not within the stated tolerance of the instrument. Finally, at 50m, the errors are within the specified tolerance and the claim accuracy of the instrument.

For the second case study, all error vectors for different colour targets are within the specified tolerance of the instrument.

These results could be suggested therefore that at very close distances (of under 10m) very reflective surfaces give unreliable results. The reason for this is that too much data is being returned to the instrument. Moreover, at distance of 40m, all error vectors are not within the required tolerance of the instrument.

It can be concluded for the first case study that, except the errors in distance measurements (of under 10m) to all colour targets, and at distance of 40m, all other errors in distance measurements are within the specified tolerance ± 10mm and the manufacture claim accuracy of the instrument and give reliable results . In addition, for the second case study, all errors in distance measurements to different colour targets are within the stated tolerance of the instrument using prismless mode. The effect of vertical and/or horizontal angle of incidence, beam divergence and the reflectivity of the surface of the object on the accuracy of observations was already discussed in section (3.2).

Finally, atmospheric and visibility can affect the measurements by prismless instrument, but all the trials observations were taken under the same atmospheric and visibility conditions.

However, further investigations will be required to observe the targets many times (e.g., say 20 measurements).

For determining the mean square error (σ) of the observed slant distances and at different vertical angles in

order to assess the accuracy of observed distances and using different materials such as, brick, marble , polished stone, painted surfaces, plastics, dressed timber, as well as metallic surfaces (stainless steel, aluminum , ...etc.). Additionally, in the present study, F.L and F.R. observations were not studied deeper.

There could be some error in the coincidence of the sighting cross-hairs and the laser signal. It must be noted that the instrument has been checked for laser mis-alignment and small error within the claim tolerance of the instrument was found.

3.5 Results of the observations to a vertical wall surface

The results of this trial were shown in Figure (8). In the case of prismatic measurements, the errors in heights increases as the vertical angle of incidence increases. Positions one to four all have acceptable errors (within the instrument specifications), but position five with the vertical angle of coincidence 40 degrees has a large error (12 mm).

But, for reflectorless mode observations, positions one to five all have an acceptable error , but positions six and seven with vertical angles 45 and 47 degrees have large errors (12mm, 13 mm) respectively.

This small data set will not give a concrete conclusions, but it can be used as a general guide only. It can be concluded that the errors in heights increase rapidly as the vertical angle of incidence increases. Positions one to four all have acceptable errors (within the instrument specifications), but position five with the vertical angle of coincidence 45 degrees has a large error.

The current test was made at small scale (close setup to the observed object) . This could affect the results due to the errors in the signal divergence and in signal coincidence with crosshairs. If the same test was performed on a greater scale the results could be different. To increase the accuracy of the test , diagonal eye piece can be used. However, the results will give some indication of the accuracy of the observed heights with vertical angles of incidence and can be used as a guide only.

4. Conclusions and Recommendations

The current study have been carried out only on the TOPCON Pulse (Prismless) Total Station GPT-2006 with special application to surveying the buildings. However a non-prism measurements technology is quite similar between all Total Station equipment, it is likely these conclusions can also applied to other instruments as a generality. The following points can be concluded :

1. Accuracy of prismless total station observations depends mainly on the power of the signal, which is reflected from the reflecting surface. The intensity of the returning signal depends on the distance from total station, the angles of incidence on the reflecting surface, and the reflectivity of reflecting surfaces which have different colours and made from various materials. These conclusions will be stated for each case in sequence.

2. This study has confirmed that while observations at right angles to an object (building) are generally well within manufacture specifications (σ=±10 mm), observations to surfaces from a position that is not at right angles to the surface of the object (signal beam) can introduce errors. However, if the horizontal angle of incidence is less than thirty six degrees from the normal, the results are within the instrument tolerance (σ=±10 mm) mm. As the angle of incidence of the signal measurement increases past thirty six degrees the error increases rapidly.
3. There are instrument limits for direct measurements to internal and external corners. Internal corners can measure up to 35 m, while external corners are accurate up to only 20 m, as a maximum distance.

Also, the internal corner always measured short, while the external corner always measured long.

4. When measuring to highly reflective surfaces from close range (less than 10m) , errors in the measurements have been occurred. Also, measurements were taken at 40m distance, the errors exceed the stated tolerance.
   The resulting error of measuring distances for white colour target (Al Capony) is less than the error of any other targets colour, hence the surface has the strongest reflectivity for the reflectorless.

   Total Station ray as compared with any other surface colour targets. The surface of the black target has a very low reflectivity, so it absorbs more energy. The black target was the worst reflecting surface and the white target was the best.

5. In the case of the observation to a vertical surface, the errors in heights increase rapidly as the vertical angle of incidence increases (more than 45 degrees) . As the horizontal and vertical angles of the reflecting surfaces increase , there will be an increase in the measurement errors.
6. It can be concluded from the results of the surveying the white concrete building by reflector and reflectorless modes that in general, the error vectors are increasing as distance from the instrument position increases.
   For external corners points, the values of the errors of the most points are not within the instrument specification accuracy (± 10 mm), but they are within the plottable accuracy (± 0.2 mm) at the engineering plan scale 1/1000 or larger. It can also be noticed that the external corners are always measured long. But, for internal corners points, the error vectors of the most of these points are within the specified instrument accuracy (±10mm) and plottable accuracy of the automatic plotting (± 0.2 mmm).
   Moreover, all the horizontal angles of incidence to these points are between 10 to 44 degrees. However, the measurements to these points are always measured short as stated above. In addition, for wall points, the displacements (errors vectors) are not within the instrument accuracy specifications, but they are within the plottable accuracy for plotting the engineering plan at scale 1/1000 or larger. Therefore, it is advisable to establish a control network points near the required building with a multitude of separate instrument setups and the horizontal angles of incidence to the detail survey points are between (–36 to +36) degrees from the normal.

7. The above field surveying tests for accuracy have been checked with the claim instrument's specifications. Further investigations will be required to check the results of these tests with the analysis of the theoretical study on the accuracy of the reflectorless total station. Where , a comparison study between the coordinates (positions) of the detail survey points of a test area (e.g., building) should be performed, using reflector and reflectorless total stations. Moreover, the results of these experiments will be published at a later date.

8. Further investigations will be required, such as, the use of other reflectorless Total Station equipment, models and different makes. Other variables include surveying the buildings covered with AL-Capony of different colours and different buildings which are covered with marble , stone , concrete, brick, dressed timber and metallic (Stainless steel, aluminum …etc.) finished surfaces. Also, using increased distances for each test, especially, In the case of measuring to a vertical surface.

9. One important thing is for all users of the prismless equipment to realize that just because the instrument can take a distance reading, it does not necessarily mean that it is correct. The use of non-reflector measurements must be checked. As always, the surveyor needs to check any observations taken by the equipment which must be within the specified tolerance for a particular survey work to satisfy the clients needs.

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تحقيق في دقة قياسات المسافة لجسم بأستخدام المحطة المتكاملة وبدون عاكس

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المستخلص :

لكي نحصل على النتائج التي تتطابق مع المواصفات الفنية لاي مشروع ، مثل هندسة المساحة (مسح الابنية) ، حيث أن معرفة الموثقية والدقة لاجهزة المساحة أمر حتمي . ألمحطات المتكاملة بدون عاكس تستخدم في هذه الايام ولعدة تطبيقات في أعمال الهندسة المدنية بسبب الدقة العالية ، سهولة وسرعة القياسات في عملية القياسات الاتوماتيكية.

تم التأكيد في هذه الدراسة على أن ألقياسات على جسم (بناية) بصورة عامة ضمن مواصفات المعمل (σ=±10ملم) ؛ القياسات للسطوح من مكان والتي ليست بزاوية قائمة على ذلك السطح من الممكن حدوث أخطاء . في هذا ألبحث ؛ تم التحقيق بالدقة والحدود لجهاز المحطة المتكاملة بدون عاكس وخصوصا لقياسات زوايا السقوط الافقية وألرأسية ذات القيم العالية على سطح عاكس ، اللون النوع وانفراج الشعاع للموجة المقاسة . تتضمن هذه الدراسة على عدة فحوصات مساحية حقلية مختلفة بأستخدام عاكس وبدون عاكس . وقد تم استخدام جهاز المحطة المحطة المتكاملة وبدون عاكس **(TOPCON GPT-2006)** لغرض تقييم الحدود والدقة لهذا الجهاز في مجال مسح ألابنية (قياسات المسافة .

نتج عن هذه الدراسة بأن زوايا السقوط للموجة المقاسة على نقاط بناية (أركان داخلية ؛ خارجية ونقاط السطح) لها تأثير كبير على دقة هذه القياسات ؛ حيث تم التوصية لاستخدام زوايا السقوط الافقية لتفاصيل ألابنية تتراوح بين (**36°-** الى + **36** °) من العامود . يضاف الى ذلك في حالة القياسات على سطح عامودي بأن أكبر زاوية رأسية هي **40°** بأستخدام العاكس **50°** بدون أستخدام العاكس للقياسات . وقد تم أقتراح عدة طرق للقياس مع توصيات للتغلب على هذه المشاكل .ألفهم الجيد لهذا ألنوع من الاجهزة مهم لغرض الحصول عتى الدقة المطلوبة للمشروع.

عندما تستخدم أجهزة أخرى من المحطات المتكاملة وبدون عاكس ؛ نتائج هذه الدراسة يمكن أن تستخدم كدليل فقط . تم أستخدام عدة برامج حاسوب **(EXCEL 2010, Auto Cad 2010)** مع برامج المربعات الصغرى لغرض حسابات وتحليلات نتائج هذه التجارب وتحليلها وعرضها على شكل جداول أو رسومات.

الكلمات المفتاحية : المحطة المتكاملة بدون عاكس ، الدقة ، مسح ألابنية ، زاوية السقوط ، السطوح العاكسة ،اللون ، النوع ، أنفراج الشعاع ، نظرية المربعات الصغرى .

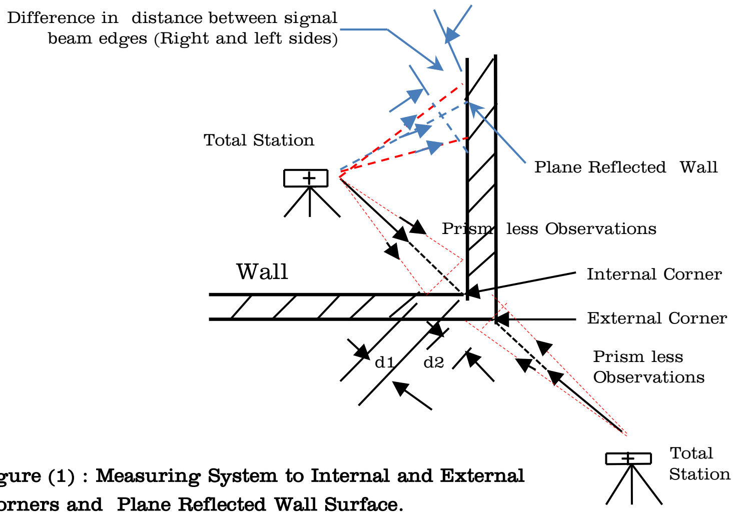

Figure (1) : Measuring System to Internal and External Corners and Plane Reflected Wall Surface.

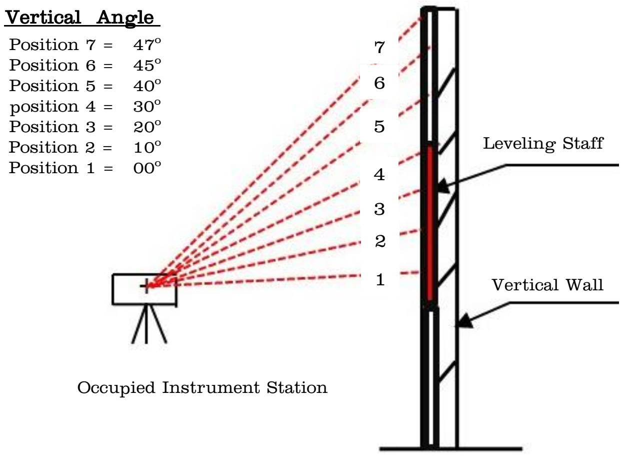

Figure (2) : Observations to a Vertical Wall.

Table (1) : Topcon GPT-2006 Pulse Total Station Perpendicular Accuracy Test.

Distance (m)	10.008	30.162	49.993	69.962	90.162	109.747
Error (mm)	00	00	02	01	00	03
	01	01	00	03	01	00
	02	02	02	04	01	02
	03	01	02	01	03	03
	04	02	04	02	02	02
	01	00	01	00	02	02
Range (mm)				4		
Mean (mm)	1.80	1.00	1.80	1.80	1.50	2.00
Std. Dev. (σ) (mm)	± 1.34	± 0.82	± 1.21	± 1.34	± 0.96	± 1.00

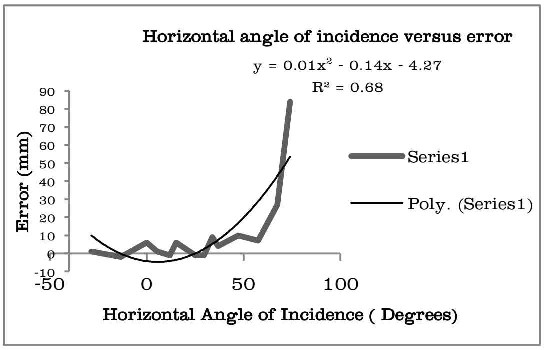

Figure (3) : Horizontal angle of incidence versus error

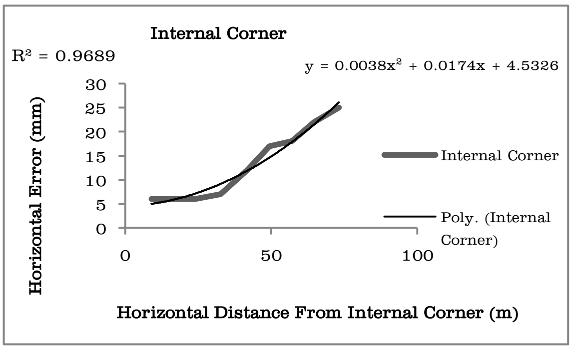

Figure (4) : Errors in the measured horizontal distance to Internal Corner.

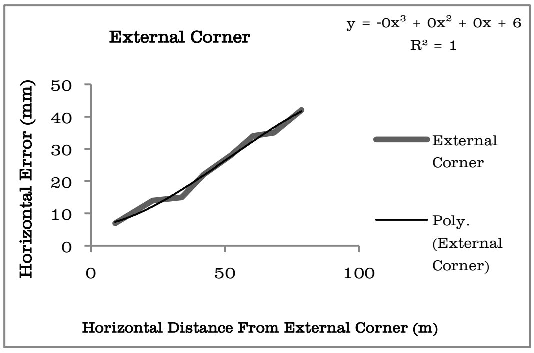

Figure (5) : Errors in the observed horizontal distance to External Corner.

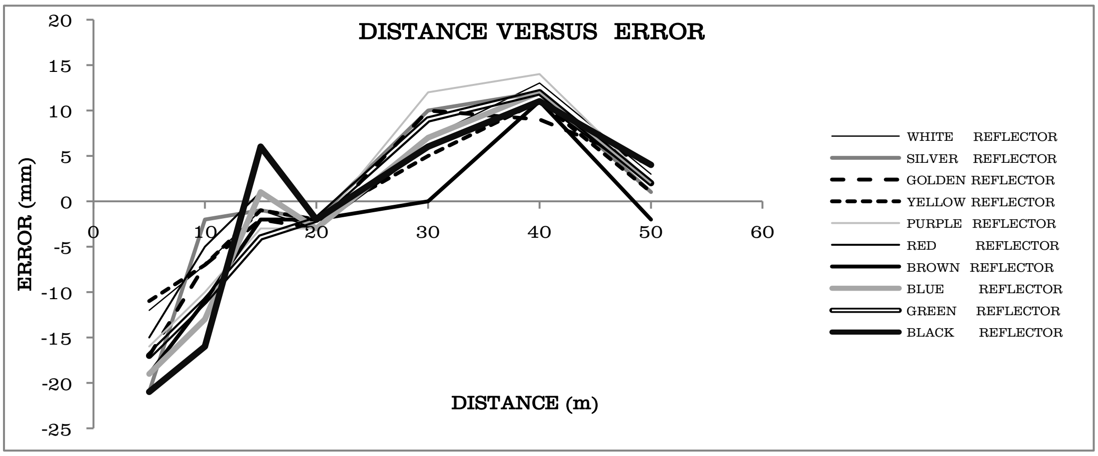

Figure (6) : Comparison the errors of distances measured by reflectorless total station for different coloured targets using the prism diatance as a standard.

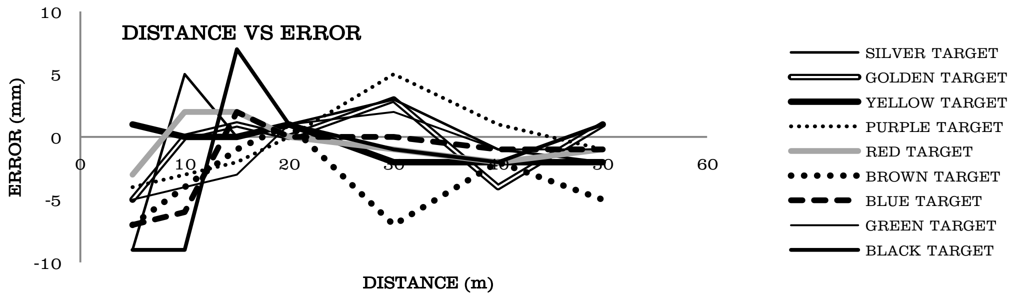

Figure (7) : Comparison the errors of distances measured by reflectorless total station for different coloured targets using the white target diatance as a standard.

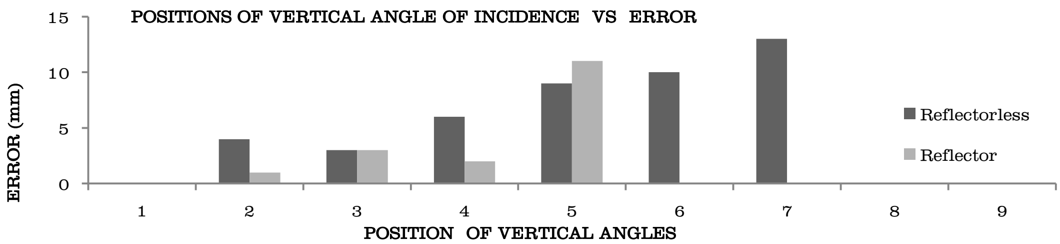

Figure (8) : Errors when measuring to a vertical wall surface (vertical angle positions versus errors)