Studying the factors affect for the accuracy of reflectorless Total Station observations

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Abstract: ***It is important to study the reliability and accuracy of modern survey instruments before using them for a specific task like engineering work or change detection studies. Reflectorless total stations are widely used in most of survey works due to their fast data collection, higher accuracy and automation procedures. On the other hand they might give low accurate results in some data collection procedures because of the variety of constrain that affects the measurement. It is possible to identify several factors affect for these observations. This paper investigates the influence of inclined angle, colour and type of the reflecting surface, effect of existing battery capacity of reflectorless total station and beam divergence for their measurements. If the instrument is used to collect precise data for a long time, above factors are subjected to affect for the accuracy of the data in a considerable manner. Therefore it should be investigated.***

Keywords **:** *Total Station ; Change Detection; Reflecting Surface*

1 INTRODUCTION

Total Stations play a major role in present survey works because of their efficiency, simplicity of operating the instrument and reliability of the work. Total station has been widely applied in engineering and industrial surveying systems to measure distances and angles automatically. (Zhiguo Xia et al, 2006). It is an improved version of survey instruments. Total Station is a combination of an electronic theodolite and an electronic distance meter (EDM). This combination allows determining the coordinates. Modern total stations have the ability to get measurements for inaccessible points such as building corners in a distance up to 1 km from the instrument with + or - 3mm accuracy. All experiments have been done under the laboratory conditions by the manufacture for above results. There are many applications of total stations such as deformation monitoring, tunnel survey, earth work and volume calculations, cadastral, setting out works and construction. Structure deformations can be determined using reflectorless total station observations.

Although the manufacturers have designed them to use under specific conditions; it is difficult to keep these conditions in practically. Therefore these error sources have to be discussed. Among these sources of errors, this paper focused on the effect of inclined angle of targets, its colour and surface types, Total Station battery capacity to the accuracy of reflectorless Total Station observations.

When addressing these influences, used measurements and the analysis of observations have performed using least squares adjustment and shown here. Reflectorless total stations are very useful in taking measurements for remote features. Taking measurements for building corners, building roofs, high ceilings and other inaccessible points can easily be done without a prism. Although it increases the efficiency of work, it is required to check the accuracy of these measurements.Reflectorless total station works similarly as a simple total station because it calculates the slope distance to the target and with the help of horizontal and vertical angles it will show the coordinates of the point.

According to the theory of reflection that the incoming ray from the reflectorless total station and reflected ray by the reflection surface lie in the same plane and their angles with normal to the reflecting surface are same for uniform surfaces.

Therefore the incident angle, type and the colour of the reflection surface would partially affect to the incoming EM energy of the reflected ray to total station as well as accuracy of instrument observations. So it is required to check inclined reflecting surfaces which have made of different colours and materials. The effect of inclined angle of reflecting surface, its colors and types on the accuracy of reflectorless total station measurements was previously investigated using Leica TCR 405 instrument (Beshr and Elnaga, 2011).

2 Investigating the influence of inclined angle of the reflecting surface, its color and type (reflector uncertainty) on the accuracy of reflectorless total station observations

Total station has a laser gun which emits a laser beam towards the target and it is reflected by the surface, back to the receiver of the reflectorless total station. Many structures such as tunnels, high-rise buildings, dams and other inaccessible features have to be measured in order to identify their deformations for further works. Since reflectorless total stations have to be used due to remoteness of data points, the influence of the characteristics of reflecting surface on their observation accuracies have to be analyzed.

Figure 1 shows Sokkia Cx 101 1” reflectorless total station which was used for all investigations.

Figure 1

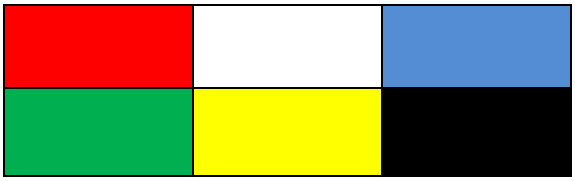
Angle measurement	Minimum display			1"
	Accuracy			1"
Measuring range:	With prism			to 5,000 m
	Reflective sheet			1.3 to 300m
	Reflector-less	(White)		0.3 to 200m
		(Gray)		0.3 to 80m
Accuracy:	Using prism	Fine measurement		2 mm ± 2 mm/km
		Rapid measurement (single)		5 mm ± 2 mm/km
	Using reflective sheet target	Fine measurement		3 mm ± 2 mm/km
		Rapid measurement (single)		6 mm ± 2 mm/km
	Reflector-less	(White)	Fine measurement	3 mm ± 2 mm/km (0.3 to 100m)
				5 mm ± 10 mm/km (over 100 to 200m)
			Rapid measurement (single)	6 mm ± 2 mm/km (0.3 to 100m)
				8 mm ± 10 mm/km (over 100 to 200m)
		(Gray)	Fine measurement	3 mm ± 2 mm/km (0.3 to 45m)
				5 mm ± 5 mm/km (over 45 to 80m)
			Rapid measurement (single)	6 mm ± 2 mm/km (0.3 to 45m)
				8 mm ± 5 mm/km (over 45 to 80m)

Table 1

The table 1 shows the manufacture specifications of Sokkia Cx 101 1" Total Station.

In a Total Station the emitted laser beam from the laser gun is reflected by the object surface and reflects back to receiver. On the other hand, Reflected laser beam has an angle which is equals to the angle of depression. Since the energy of reflected laser beam depends on nature of the reflecting surface, it is important to investigate its influence on the accuracy of total station observations. When determining the tilt of a tower or deformations of other inaccessible structures, it is required to analyze the accuracy of total station observations on various targets which have made of different materials and colors.

First study was executed in order to determine the effect of reflecting surface skin color. Sokkia Cx 101 1" reflectorless total station was used for data collection. In the case of investigating the influence of surface color on the accuracy of Total Station observations, six different color plates were used. To avoid the influence of surface roughness, painted glass plates were used. Following procedure was used for the data collection. Seven color (White, Black, Red, Green, Brown, Yellow and Blue) target plates were used for the data collection.



Color plates used for surface reflectivity

Figure 2

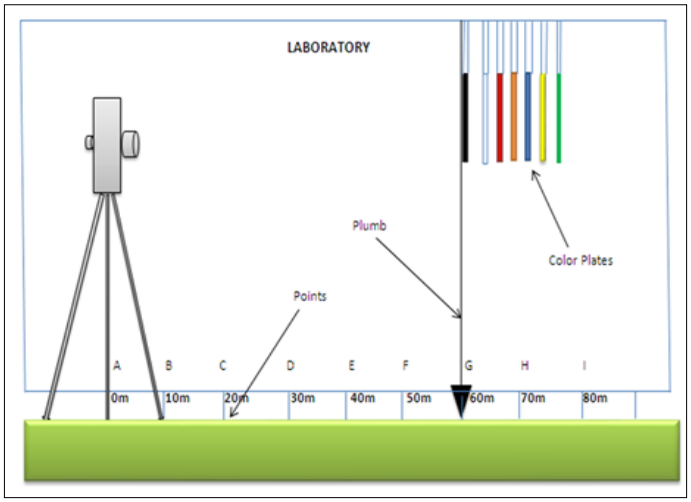


Figure 3

Glass plates were used to keep the surface smoothness and they were painted with non-transparent paints. The experiment was done under laboratory conditions. The temperature was kept at 29C°, humidity 10ppm, Air pressure 1013Pa.Always tried to avoid the influence of environmental and target factors unless the target color. Each colored target was set at B to I positions as the figure 3 and a set of 30 measurements were taken for each color plate while suspending at each point. Points were laid approximately 10m gaps and the horizontal distances from the instrument station to each point were measured very precisely by the total station for both the face using a prism target.

Figure 4 shows the results of the study. Its X axis represents measured horizontal distances and Y axis represents mean square error of respective distances. The horizontal distance measured to the prism was used as most probable value. Mean square errors of each color in reflectorless mode were determined using following equation 1.

$$rms = \sqrt{\frac{\sum_i^n (x_{rl} - x_r)^2}{n}} \quad (1)$$

Where rms is the root mean square, x_r is the distance by reflector for each data set; x_{rl} is the distance by reflectorless measurement and n denotes the number of observations.

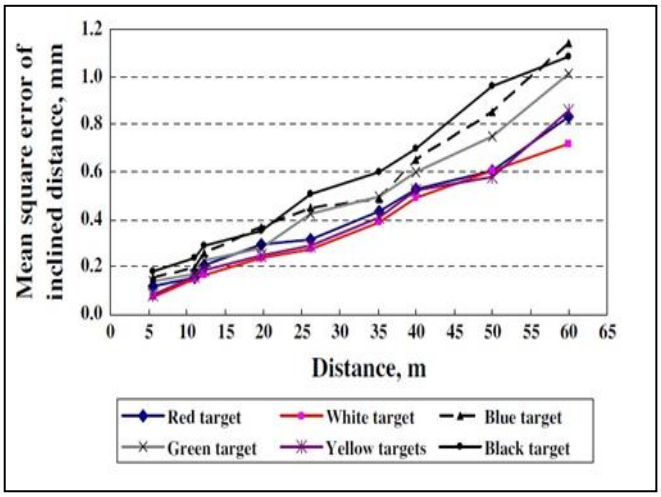


Figure 4

Above graph is prepared for six color targets. It is understood that when increasing the distance between total station and the target affects for increasing the error in measured distance for all colors. Accuracy of measured distances for white target was more accurate than all other color targets. Hence this white surface has the highest reflectivity for reflectorless Total Station ray as compared to any other surfaces. Black target has low reflectivity since the black color absorbs more energy from the incoming laser ray.

The next test was done to investigate the influence of inclined angle of the reflecting surface on reflectorless Total Station measurements. Since the inclined angle of the reflecting surface has a significant influence on the energy of the reflected ray from the surface to the total station and therefore the accuracy of its measurements. The test was carried out using Sokkia Cx 101 1" set and it consist of two separate practical tasks. The first task was carried out to investigate the deference between prismatic option and prism less observations with respect to different inclination angles. Second test was carried out to check the accuracy of reflector less observations with respect to different inclination angles.

Rectangular white target was used for the study. White target was fixed on a smooth wall of a building in southern campus. It is assumed that the influence caused by wind, temperature and humidity is infinitely small. Ink marks were made along a vertical line with an interval of nearly 3m.

Horizontal distances were then measured with reflectorless mode and the observations were recorded. This was performed from a distance of 20.59 m. The same set of observations was taken with reflector mode in order to compare the observations. As a check for control data these points were again measured by using another Sokkia Cx 101 1" total station. Above test consist of determining the standard deviations of 40 observations for each incident angle to a prism and a white target. Following figure 5 shows the difference between reflectorless and reflector observations for different inclined angles of the target.

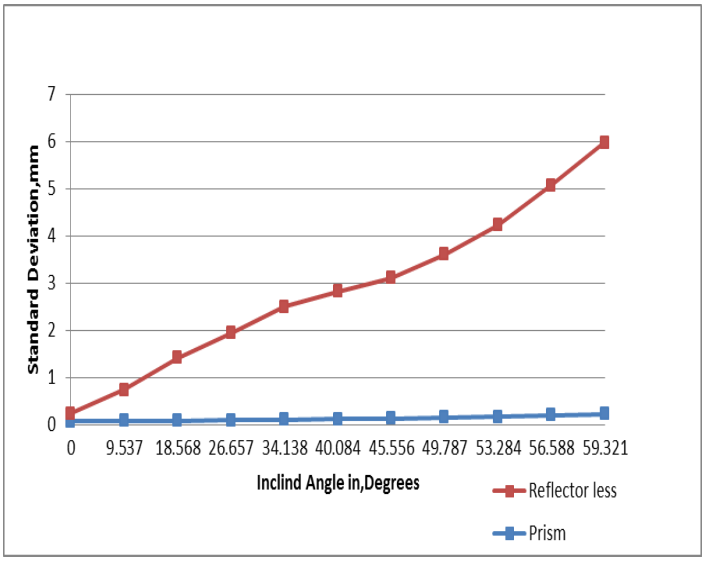


Figure 5

Inclination angle in Degrees	Mean Square Error in mm	
	Prism	Non prism
0.000	0.061	0.168
9.537	0.071	0.649
18.568	0.080	1.347
26.657	0.087	1.855
34.138	0.101	2.400
40.084	0.113	2.701
45.556	0.125	2.973
49.787	0.147	3.461
53.284	0.160	4.046
56.588	0.192	5.165
59.321	0.215	5.866

Table 2

This study clearly explains two important factors. It says that when increasing the inclination angle of the reflecting surface will increase the error of measured distance. On the other hand for a same inclination angle the observed error of a distance from an object is considerably greater than from a prism.

Another data set was taken for rectangular white target and prism target in order to compare the results. Distances were selected in a range of 0 – 160 m. There were twenty observations taken for each distance to the white target as well as prism. The horizontal distance and inclination angle (0^0) were kept as a constant for particular data set. Following table shows the observation set taken to both reflectorless and reflector observation mode.

Distance (m)		7.85	33.94	69.58	96.72	135.86	151.06
The Mean Square Error (mm)	The prismatic option	0.034	0.095	0.152	0.185	0.217	0.238
	The reflector-less option	0.066	0.102	0.346	0.783	1.053	1.161

Table 3

Next text was performed to investigate the effect of reflecting surface material on the accuracy of distance measured by the reflector less Sokkia Cx 101 1" total station. Four different targets made of four different materials were used for the study. They were Cement, Brick, Steel and Wooden. This test was carried out inside a building in the same university at 30 C^0 temperatures. All targets were set at a 15.271 m distance from the total station. The horizontal distances for 20 observations of each target were recorded and standard deviations were calculated.

The mean square errors of horizontal distances measured from reflectorless total station for different targets are as follows.

Material Type	Mean Square error in mm
Cement	0.312
Brick	0.207
Steel	0.321
Wooden	0.245

Table 4

It is understood that the surface material has a significant influence on the accuracy of reflectorless observations. The brick target had the minimum mean square error so the accuracy of observations was higher. Steel targets had the lowest accuracy.

3 Investigating the effect of battery capacity on the accuracy of reflectorless total station observations

When using reflectorless total stations for long time in the field, the quality and accuracy of measurements may be affected by the existing battery capacity of the instrument. This study was carried out inside a building in southern campus at a temperature of 28 C^0. The Sokkia Cx 101 1" total station was used with an accuracy of 3mm/km for reflectorless measurements. Above mentioned accuracy is given by the manufacturer under the laboratory conditions. But it is really interesting to investigate the behavior of the accuracy when it is used in the field for a long time. The test started on 7:00 am and continued to 12:45 pm (the period of battery work equals 5 hours and 45 minutes) and observed 10 observations after every 25 minutes. All horizontal observations were then recorded. There were no changes in horizontal and vertical angels of the instrument while getting observations. A distance of 10m was selected in order to minimize the error due to atmospheric effects. The graph was constructed using the results and its X axis represents the time from starting battery work and Y axis represents measured horizontal distance.

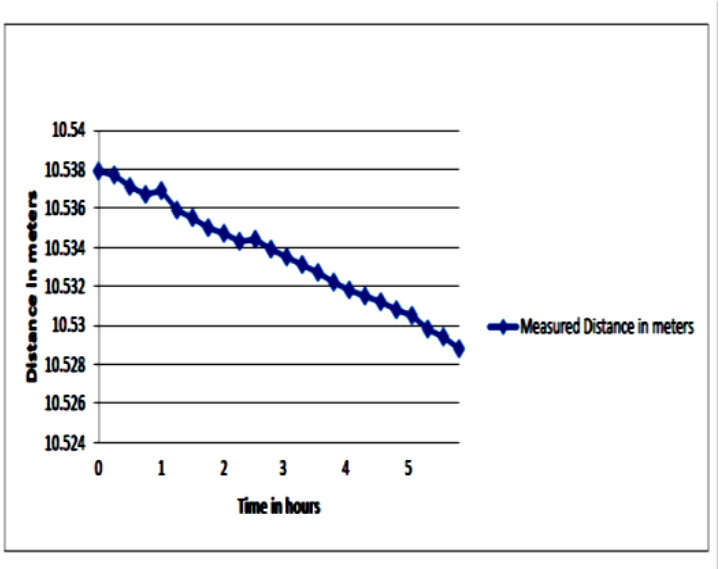


Figure 6

It is observed that the distance has reduced by an amount of 9mm throughout the observation period.

4 Investigating the effect of beam divergence on the accuracy of reflector less total station observations

Other than reflector uncertainty the beam divergence is the next reason which affects for the accuracy of reflector less total station observations. As the size of the laser spot increases with the distance from the total station, the accuracy of the measurements goes down. For an example, when measuring a 40 mm diameter pipe line from a 50m distance would be difficult since the laser foot print has a diameter of 100mm signal for the Sokkia Cx 101 1" total station.

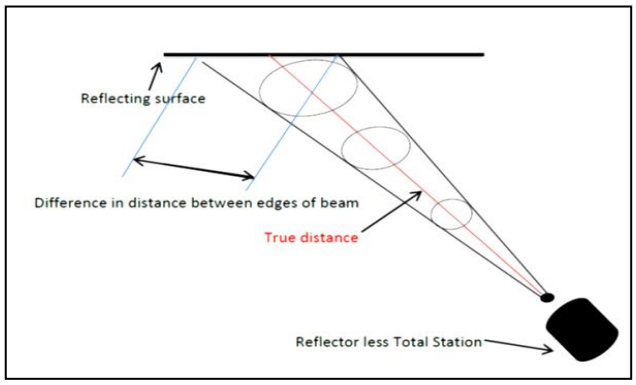


Figure 7

The grater the laser beam divergence, the larger the size of the laser dot on the surface. According to above figure there are two portions of the error occurred by laser beam divergence. They are the size of the dot on the reflected surface and angle of incidence with the surface. The angle of incidence can be reduced by moving the instrument to a distinct position. Unfortunately it has the effect of increasing the size of the laser dot. Solution would be to set up the instrument with a perpendicular angle to each measurement. This would allow to have more certain observations but this is either impracticable. Laser beam divergence varies with the manufacturers having a range in size from 9*28mm to 100*110mm at a distance of 50m from the instrument. It is 20*20mm/50m for Sokkia Cx 101 1". Final study was carried out in order to determine what distance a small size feature could be measured before the laser beam get diverge. A bolt was fixed on a half tall wall surface.

The accurate distance between the wall and total station was measured with the help of a prism target placed over a half wall. Then the accurate distance from instrument to nail head was calculated by subtracting the bolt head protruded from the wall surface. The distance measuring was started with reflector less mode from a close range and once the reflector less measured distance deviated with the actual distance, it is assumed that the laser beam had a divergence which was negatively affected for the accuracy of reflector less measurements. Two bolt heads were selected randomly. First had a diameter of 10mm and second had a diameter of 20mm. surrounding background of the bolts were white and always kept the inclination angle perpendicular to the surface.

Figure 8 shows the nail having 10mm diameter which was set to the half tall wall.

Figure 8

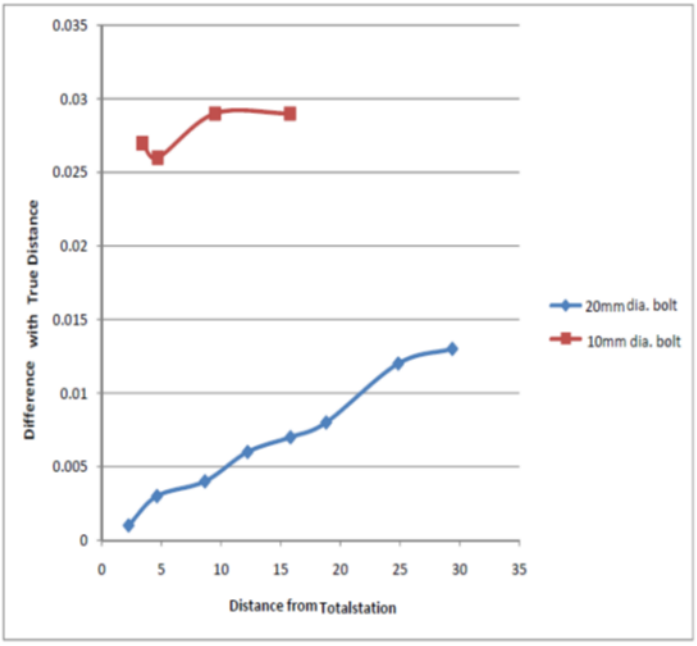


Figure 9

As figure 9 shows, small objects are difficult to measure from the instrument. The bolt head with 10mm diameter was difficult to read with a reasonable accuracy. Target with 20mm bolt head has an error less than 5mm up to a distance of 10m.

5 Conclusions

Based on the analysis of above study, following conclusions can be shown.

(1) The accuracy of the measured distance by reflectorless observation has a convergence with reflector observation for short distances. The maximum distance is 35m for a better accuracy.
(2) The error of distance measurement increases if the inclination angle of the reflecting surface is increased. It is better to keep the observations for targets having inclination angles less than 30^0.
(3) Reflector less observations accuracy is higher if the target has white skin color.
(4) Error of slope distance measured by reflectorless option is increased when the battery capacity of the instrument decrease.
(5) Brick target gives the higher accuracy for distance measurements than any other target. Target made of metal has the low accuracy.
(6) According to the theory of beam divergence larger targets can have greater accuracy up to 30m of distance from the instrument.

6 References

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