Accuracy Analysis for Total Station Based on the Reflectorless Distance Measurement Using ANOVA

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Abstract - Reflectorless distance measurement (REDM) was used to form various platforms in specific total stations for engineering projects, land surveys etc. It provided rapid measurement by saving time and field hands for surveyors; hence, the reliability of the measured distance from an object has great importance. Also, it increased personal safety without approaching unsafe surfaces. This study aimed to investigate the accuracy difference between the reflector and reflectorless distance of the total station with ten different materials and two different environmental conditions. The study was conducted outdoor using Sokkia SET530R and Trimble M3 total stations. Ten different materials were tested typically in construction fields. Two different conditions were investigated, including dry and wet targets. Two dissimilar incident angles were also inspected, 000 and 300 respectively. The experiment was evaluated by taking the reflector reading as true value to check the accuracy of reflectorless measurement. It concluded that Sokkia SET530R total station gained deviations between 12-23 mm for all conditions and incident angles. The Analysis of Variance (ANOVA) tables proved that eight materials were reflected with good accuracy except for granite and plywood materials for the Sokkia total station (P<0.05). In addition to that, the results of all materials showed a deviation between 5-8 mm for Trimble M3 total station at an incident angle of 000 for both dry and wet conditions.

Keywords: *ANOVA, reflectorless, total station*

I. INTRODUCTION

Technology has become more influential in many ways of surveying as in many professions. Computer technology and Auto CAD packages allow us to design, store and manage geospatial data, while at the same time technology engages in faster data collection with increasing of speed and accuracy. One of such pieces of technology is the reflectorless measurements, also it is known as prism less total station. In this measuring mode, the laser beam directly reflected from the measured surface.

A total station is an electronic surveying instrument. It combines Electronic Distance Measuring Equipment with an electronic theodolite and a computer. The electronic theodolite measures the angle in two ways, such as horizontal plane and vertical plane. The Electronic Distance Measurement (EDM) takes measurements by using the LASER (Light Amplification by Stimulated Emission of Radiation) technology (Key & Lemmens, 2005). The effect of the incident angle of reflecting surface, its colours and types on the accuracy of reflectorless have been examined recently for the total station (Zámečníková & Pegritz, 2014). The instance of the reflectorless distance measurement is diffused reflection as the pulse reflected in all directions and the reflected light rays are scattered (Evangelia Lambrou, 2018). Additionally, some multipath error may be occurred and it would be an increased error. Therefore, it would effect on the final calculated distance. Accordingly, the impression of the material is also a main parameter. Based on the material of the surface, reflection is also varied. A smooth surface has a perfect reflection, whereas rough surface has diffused reflection as shown in figure 1.

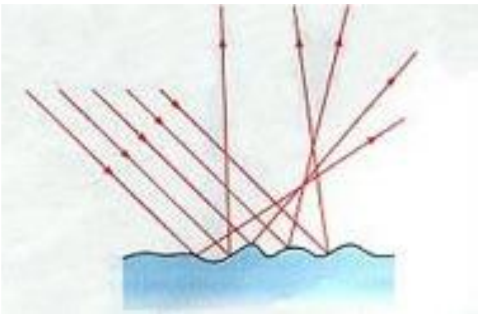

Figure 1. The diffuse reflection
Source: Evangelia Lambrou, 2018

Also, the meteorological conditions are the parameters that influence the EDM with or without prisms. For these reasons, temperature of the target surface was changed (Rüeger, 1996). So, it is important to emitted EDM signal and then it reflected back to the EDM receiver from the right point of the sighted surface.
Reflectorless technology is used in different circumstances to survey infrastructures that are inaccessible, and to improve the efficiency. Also, it increases personal safety without approaching to unsafe surfaces. Some advantages of the reflectorless distance measurement are the reduction of the time and the number of helpers. The control of the team reduces to one person, to exact targeting of points and to setting the prism is not required. Most of the projects require observing points which are not required to install a reflector on them, or are situated in a dangerous area for people to operate. In such cases, preferences are given to reflectorless total stations.
At present, reflectorless total stations are being used in several civil engineering projects for taking distance measurements. When the distance from the instrument's object is increasing, the width of the signal beam also is increasing. Due to the uncertainty of the incident angle of the material surface, REDM (Reflectorless Electronic Distance Measurements) cannot be obtained a perfect reflection from the incident ray. It has affected to the accuracy and reliability of the measurement. Also, it can affect the accuracy of the final reading. The effects of meteorological conditions are also taken into consideration. Therefore, the difference in final accuracy was which compared with the reflectorless distance, and the reflector distance was the main problem in this research.

The main objective was to analyse the accuracy of reflectorless total stations for SOKKIA SET530R and Trimble M3 with the distances and sub-objectives were to investigate the effect of the distance measurements for different materials, different environmental conditions and changing the incident angles of targets with the distances.

II. METHODOLOGY

Sokkia SET530R and Trimble M3 total stations which are currently available of the department of geodesy were used to observe the accuracy of reflectorless distance measurements. Accuracy of the instrument was 3 mm ± 2 mm /1 km in reflectorless mode for both instrument (Trimble, 2013) (SOKKIA CO., 2006). Ten materials were used with smooth and rough surfaces of different materials such as Jack wood, Rock, Granite, Brick, Tile (smooth), Tile (rough), Plywood, Steel, Aluminium and Concrete with dimensions of 0.15 m x 0.15 m. The measurements were taken in outdoor conditions with same weather condition. The test materials were fixed on a specialized steel bracket which was used to attach the materials on tribrach of a tripod. E. Lambrou used the design which I used, similar to construction of the bracket in their testing (E Lambrou & Pantazis, 2010) as shown in figure 2.

Figure 2. Special Bracket

The total stations and the target were set up at a distance of 10 m apart. The distances were measured firstly by the prism target and repeatedly on all the materials. Namely two incident angles of 0° and 30° were tested, and incident angle of 0° was considered as the perpendicular position of the material to the sighting line of the instrument.

Dry and wet conditions were tested for each material and sprayed water for wet condition to take the distance instantly. Each measurement was taken five times and mean was calculated. This procedure was done by all 10 m distance intervals up to 100 m for both total station and for each material.

A. ANOVA analyses

Analysis of Variance (ANOVA) is a statistical test, which was used to analyse the difference between the means of one or more than two groups. The two-way ANOVA was used to estimate how the mean of a quantitative variable is changed according to the levels of two categorical variables (Hasegawa & Yoshimura, 2007). Usually, two-way ANOVA is used, when you need to know how two independent variables in combination effect on a dependent variable. In this research two-way ANOVA was used to clarify the factors affecting the REDM in total stations. The dependent variable consisted of the prism distance while the independent variables were the dry and wet conditions, incident angles and materials.
The more researcher fulfilled an ANOVA analysis using disparities to perform statistical tests for differences in reflectorless distance measurements. The analysis of disparities completed using the R 3.6.1 programming. R is a free software environment for statistical computing and graphics. It compiled and ran on a wide variety of platforms. These tests confirmed that the performance of the dry and wet conditions, incident angles and materials which are significantly associated with the total stations.

III. RESULTS AND DISCUSSION

The results outlined for materials, conditions (Dry and Wet) and incident angles. Each material was charted and analysed individually to determine accuracy. Also, a comparison was made between the prism target and different material targets. Those comparisons were used to determine, if materials and conditions effect on the REDM. The prism observations were taken as true distance for all analyses, the prism distance between the control points and it presented in solid thick black line. Reflectorless distance and prism distance difference for different materials/ targets is represented in the Y- axis.

The results from jack wood and tile (smooth) materials are shown in figure 3 and figure 5 respectively. For Sokkia deviation between all measurements at different incident angles and under different conditions had 10 m interval up to 100 m. This set of data had a range of 15 mm for Sokkia SET530R and 34mm for Trimble M3. This range would be less than 8 mm if the fallouts of the dry and wet condition at 00^0 IA (Incident Angle) for Sokkia SET530R and 6 mm for Trimble M3. These two outcomes had less varying between 00^0 IA and 30^0 IA out of ten materials.

The brick material outcomes are presented in figure 7 for Sokkia SET530R and figure 8 for Trimble M3. It had arranged of 21 mm for both Sokkia SET30R and Trimble M3. This range would be less than 8 mm if the results of the dry and wet condition at 00^0 IA for Trimble M3. The general trend of the data in Sokkia SET530R relatively downward over the whole 100 m distance. With the variable differences in Sokkia SET530R and Trimble M3 at 30^0 IA were spread of graphs further down and overhead relevant to the true distance.

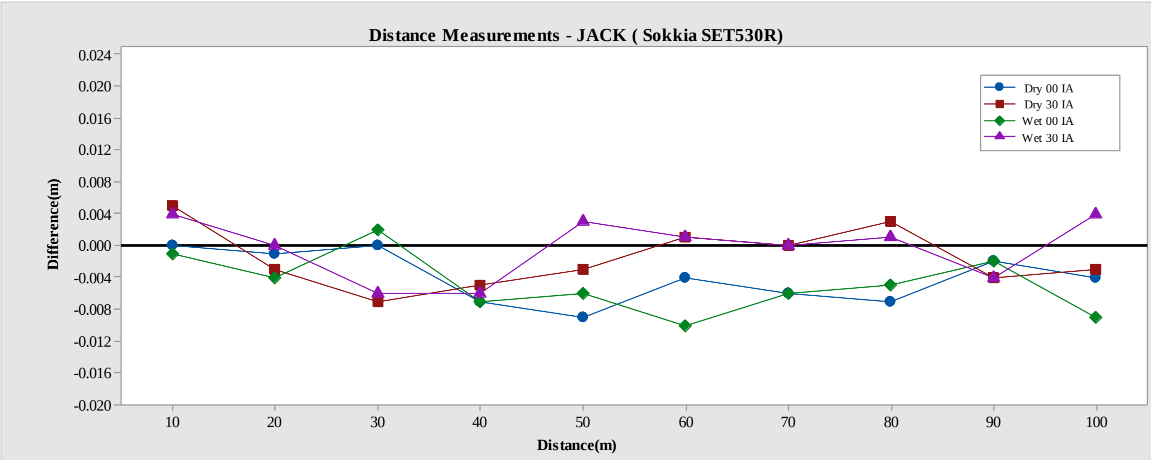

Figure 3. Distance Difference in the reflector and reflectorless distance measurement using SOKKIA SET530R for Jack wood material

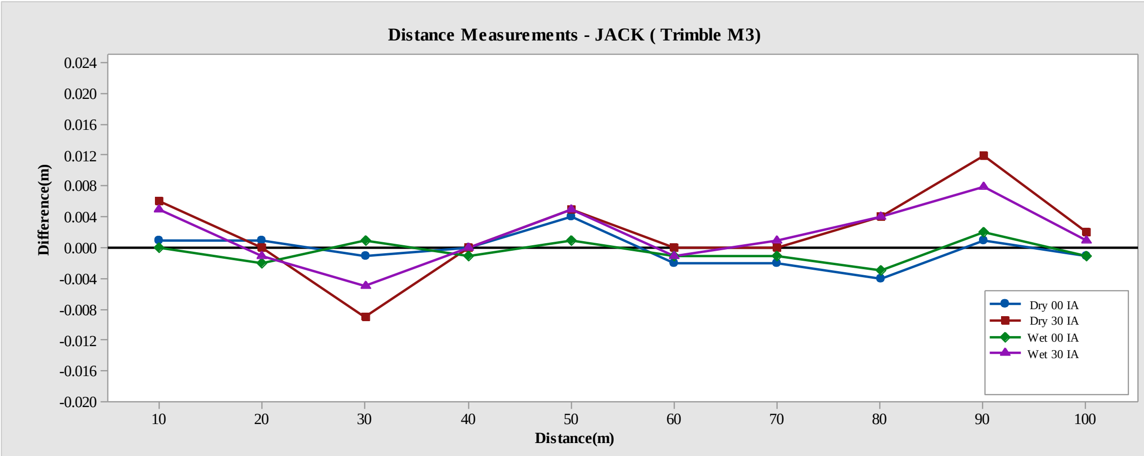

Figure 4. Distance Difference in the reflector and reflectorless distance measurement using Trimble M3 for Jack wood material

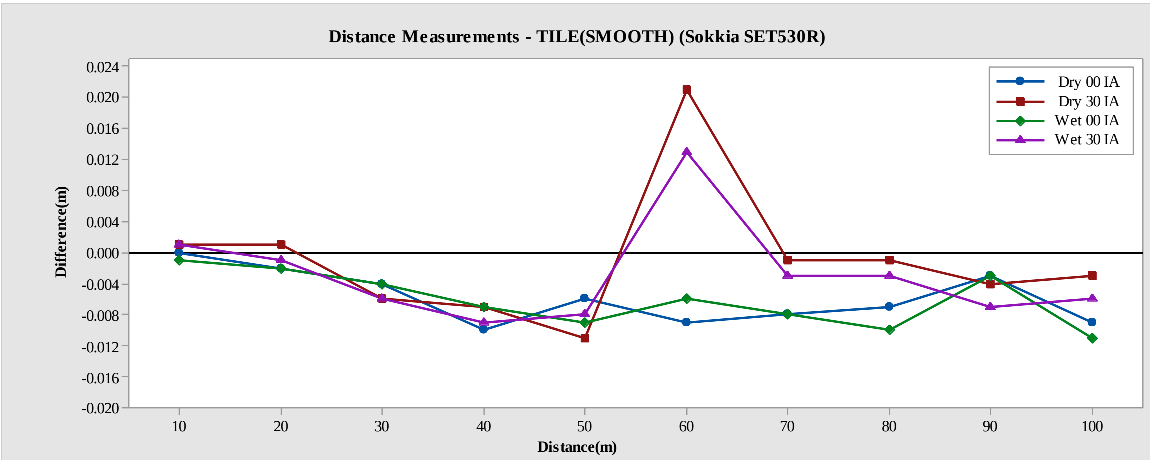

Figure 5. Distance Difference in the reflector and reflectorless distance measurement using SOKKIA SET530R for Tile (Smooth) material

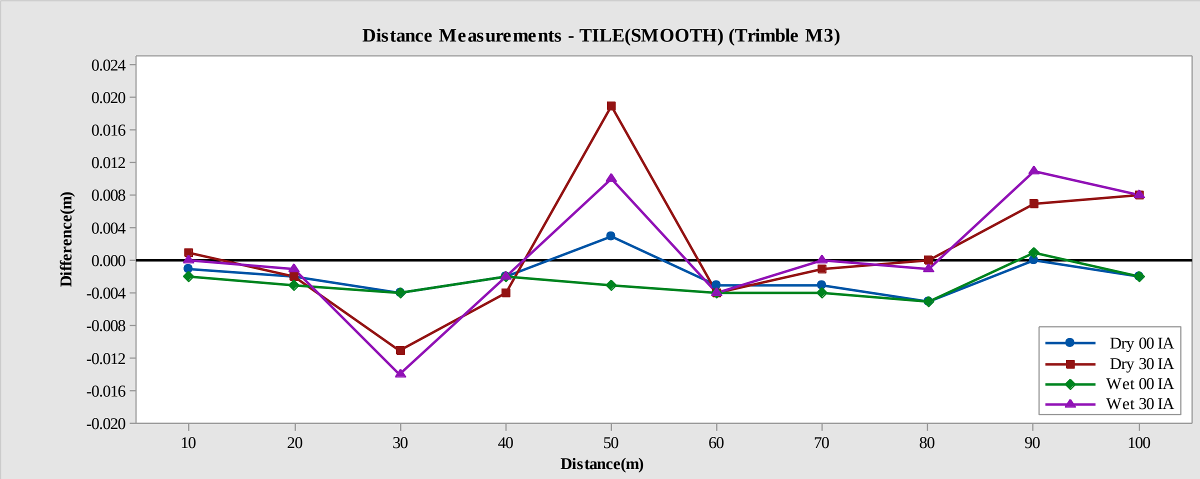

Figure 6. Distance Difference in the reflector and reflectorless distance measurement using Trimble M3 for Tile (Smooth) material

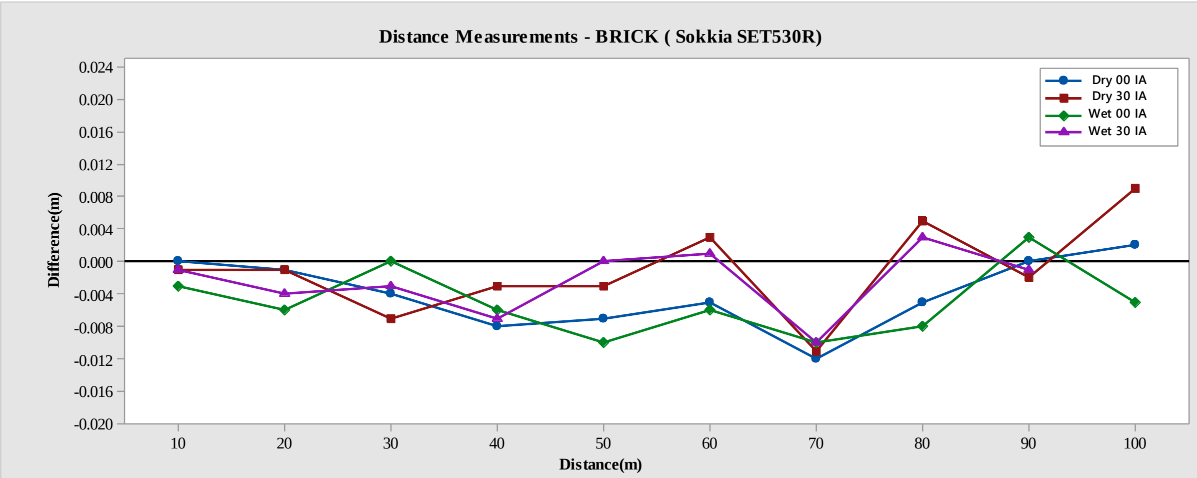

Figure 7. Distance Difference in the reflector and reflectorless distance measurement using SOKKIA SET530R for Brick material

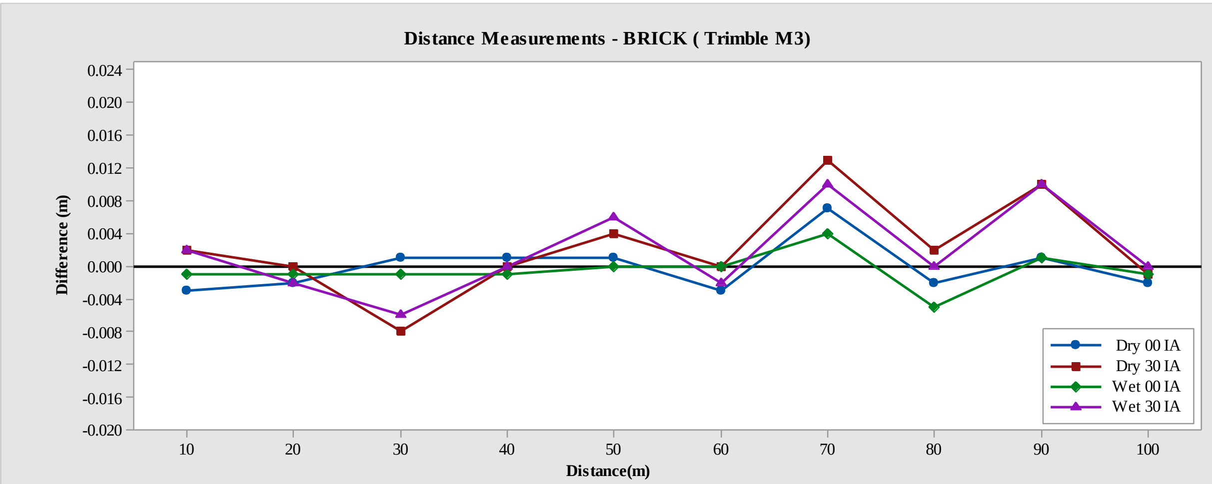

Figure 8. Distance Difference in the reflector and reflectorless distance measurement using Trimble M for Brick material

Results of ANOVA

Before ANOVA is being applied, it has to be checked whether there is a correlation between the variables. If P value < 0.05, that means there is a relationship between independent variable and dependent variable. Table 1 shows that all P values were less than 0.05 for all the materials and instruments. Then ANOVA could be applied for these variables.

Table 1. Results of correlation for Sokkia SET530 and Trimble M3 total staions.

Variable	Instrument	
	Sokkia 530	Trimble M3
	P- value	P- value
Jack wood	0.000	0.000
Rock	0.001	0.000
Granite	0.038	0.000
Brick	0.000	0.000
Tile (smooth)	0.000	0.000
Tile (rough)	0.000	0.000
Plywood	0.000	0.000
Steel	0.041	0.000
Al	0.000	0.000
Concrete	0.000	0.000

In this research, two-way ANOVA was used to clarify the factors affecting the REDM in total stations. In this analysis, tables 2 and table 3 summarize the analyses of dry and wet conditions with incident angles and tables 4 and table 5 of materials, respectively.

According to table 2 incident angle were not any significant differences (P>0.05) among the dry 30^0 incident angle (DRY30IA), wet 00^0 incident angle (WET00IA) and wet 30^0 angle (WET30IA) comparatively the dry 00^0 incident angle (DRY00IA) for Sokkia SET530R total station. The interaction effect of the three factors were also not significant. According to the table 3, incident angle has significant differences (P>0.05) among the dry 30^0 incident angle, wet 00^0 incident angle and wet 30^0 angle comparatively for the dry 00^0 incident angle. These results were indicated differences between the incident angles which are not associated with differences among the Trimble M3. Furthermore, table 4 displays that materials, were not significant differences (P>0.05) among the granite and plywood, while other all materials have significant differences (P<0.05). These results were indicated significant differences between the materials which are not associated with differences among the Sokkia SET530R without granite and plywood.

And also, table 5 expressions that, there were significant differences (P<0.05) among the jack wood, rock, granite and brick while all other materials have not a significant difference(P>0.05).

Table 2. Results of ANOVA for dry and wet conditions with incident angle for SOKKIA SET 530R total station

Source	Df	Sum Sq	Mean Sq	F value	P value
DRY30IA	1	2.567e-06	2.567e-06	2.756	0.148
WET00IA	1	1.198e-06	1.198e-06	1.286	0.300
WET30IA	1	2.486e-06	2.486e-06	2.668	0.153
Residuals	6	5.590e-06	9.316e-07		

Table 3. Results of ANOVA for dry and wet conditions with incident angle for Trimble M3 total station

Source	Df	Sum Sq	Mean Sq	F value	P value
DRY30IA	1	6.241e-07	6.241e-07	5.541	0.0568
WET00IA	1	8.885e-07	8.885e-07	7.888	0.0308 *
WET30IA	1	5.250e-08	5.250e-08	0.466	0.5203

Residuals	6	6.759e-07	1.126e-07

Table 4. Results of ANOVA for all materials of Sokkia SET530R total station

Source	Df	Sum Sq	Mean Sq	F value	P value
Jack wood	1	26691	26691	4.432e+09	0.0000 ***
Rock	1	0	0	4.569e+01	0.0000 ***
Granite	1	0	0	3.711e+00	0.0655
Brick	1	0	0	1.543e+01	0.0006 ***
Tile(smooth)	1	0	0	1.995e+01	0.0001 ***
Tile(rough)	1	0	0	1.276e+01	0.0015 **
Plywood	1	0	0	4.908e+00	0.6662
Steel	1	0	0	1.995e+01	0.0361 *
Al	1	0	0	9.817e+00	0.0044 **
Concrete	1	0	0	4.996e+00	0.0346 *
Residuals	25	0	0		

Table 5. Results of ANOVA for all materials of Trimble M3 total station

Source	Df	Sum Sq	Mean Sq	F value	P value
Jack wood	1	29707	29707	4.225e+09	0.0000 ***
Rock	1	0	0	1.511e+01	0.0006 ***
Granite	1	0	0	8.706e+00	0.0065 **
Brick	1	0	0	6.297e+00	0.0184 *
Tile(smooth)	1	0	0	1.070e-01	0.7467
Tile(rough)	1	0	0	4.000e-03	0.9532
Plywood	1	0	0	2.720e-01	0.6064
Steel	1	0	0	3.061e+00	0.0915
Al	1	0	0	7.000e-02	0.7934
Concrete	1	0	0	3.796e+00	0.0619
Residuals	27	0	0		

(* Significant at the 0.05 level, ** Significant at the 0.01 level, *** Significant at the 0.001 level, Df- Deg. of freedom, Sq-Squares)

IV. CONCLUSION

This research was able to find the accuracy of reflectorless total stations with distance in outdoor circumstances; two reflectorless total stations were tested for a distance of 10 m intermission up to 100 m with 10 materials in two different incident angles and dry and wet conditions. This experiment was evaluated by taking the reflector (prism) reading as true values. The first important finding was the limitation for the incident angle. Based on the research, it did not reflect at the incident angles of 60^0. It could be safe to say that "angles of 30^0 provide results that were reliable to any surveying task over a short distance in reflectorless mode".

By considering both graphically and ANOVA outcomes, Sokkia SET530R total station gained the fluctuation between 12 mm and 23 mm only, these differences of range were presented graphically for all materials, dry and wet conditions and incident angles. In addition to statistics, the ANOVA tables were proved that 8 materials which were reflected with good accuracy ($P<0.05$), and only two P values ($P>0.05$) were observed to granite ($P=0.0655$) and plywood ($P=0.6662$) materials for the Sokkia SET530R total station.

The effects of the dry and wet conditions on distance measurements were found statistically equal only incident angle of 00^0 for Trimble M3 total station ($P<0.05$). Besides that, the results were displayed graphically the error of variance between 5 mm and 8 mm only for all materials in Trimble M3 total station. The outcomes also were showed statistically and graphically and observations were not equal between dry and wet conditions as well as incident angle of 00^0 and 30^0 for both total stations ($P>0.05$). The deviations of the repeated measurements were indicated that "Trimble M3 total station was precise enough and had high accuracy in the reflectorless mode at incident angle of 00^0."

In this area of research, there was the possibility for further researches. A key recommendation was made which it can be conducted properly, and it will provide more knowledge to the surveyor on how REDM interacts with targets along with different materials tested. This was not limited to different materials but a combination of different colours in same material tests are also useful to understand, if there was any difference in colours of same material.

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I have Studied BSc Surveying Sciences (Surveying and Geodesy). I have an interest in modern land surveying methods and topographic surveys for engineering projects. I hope to develop a model for drone surveys in future.

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