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ANALYSIS OF THE PERFORMANCES OF FOUR TOTAL STATION INSTRUMENTS IN CONTROL EXTENSION

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ABSTRACT

In the Surveying profession, advanced and modern instruments are improving the accuracy and precision of measurement and observation. However, accessing these instruments, such as Total Stations (TS), must be done with caution. This study is aimed at evaluating and analyzing the performance of TS instruments in a horizontal control extension. To conduct this study, a closed traverse was carried out to extend horizontal control points using Leica 1201+ series TS. The observations were carried out three time for five days. The result serves as the base for comparison with other four TS instruments. The TS instruments used include: Ruide RTS-820 Series, Nikon TS DTM-352/332, Sokkia CX – 105 series, and Topcon Total Station GTW-210 Series. The four TS were used to run a closed traverse on these same reference points. The observed data was processed using the least square adjustment procedure. The Standard Deviation (SD) and Root Mean Square (RMS) of the mean coordinate values for the four TS were computed. The result shows the highest SD as 0.0137508m and the highest RMSE as 0.012663m. This signals that all the mean coordinates obtained by the four TS were relatively close to reference TS data and also, that the residuals of the coordinates did not differ significantly. The two-way ANOVA test carried out however, signifies that at 0.01 level of significance the result of the four TS instruments dose not differ from the reference TS. It is therefore concluded that, all the four TS instruments has no significant difference in terms of control extension of similar project.

Keywords: Total Station, Reference Station, Performance, Accuracy, Precision

INTRODUCTION

In surveying, control surveys are surveys that provide a rigid framework for fixing points on which a detailed survey is based, or which are used as the reference points for setting out survey work. A control survey is a survey that establishes the positions of points with a high degree of accuracy to support activities such as mapping and GIS, property boundary surveys and other engineering works. An established control network is a network of control points that provides a unified coordinate base for surveys and other related activities within a given area. The purpose of control extension generally, is to establish a network of points on the ground that are sufficiently accurate to provide control for any survey and engineering projects. These controls are classified into: zero, first, second, and third orders (Olatunde et al., 2022). The zero Order denotes the highest level of precision and accuracy, involving meticulous measurements. First Order surveys, while slightly less precise, still offer high accuracy and are employed in large-scale mapping and engineering projects. The second-order controls are controls which are usually used to control precise engineering surveys, urban control, multi-purpose control densification, inter-cadastral densification in urban areas, and extension and supplementary controls (Ikharo et al., 2019). The third order controls also known as the Secondary/Tertiary Order surveys have lower precision levels. The classification of surveys into Zero Order, First/Primary Order, and Secondary/Tertiary Order ensures appropriate level of accuracy for different projects, including scope, purpose, and intended outcomes.

Various instruments are used in surveying for control extension, TS instrument is among the instruments that are used in carrying out control extension (Aliyu and Usman, 2019). A TS instrument is an optical surveying instrument that measures both angles and distances. It combines the functions of a theodolite with that of a transit level and electronic distance meter (EDM). TS instruments measure distance by using a modulated infrared carrier signal, which is generated by a small solid-state emitter inside the instrument's optical path. Most TS instrument can measure distance with an accuracy of about 1.5 millimeters (or 0.0049 feet) plus two parts per million over a distance of up to 1,500 meters (or 4,900 feet). This is much more accurate than a GPS or any type of base station. But like any other instrument, it all depends on how well the user operates it (Leica Geosystems, 2008).

In the past few decades more sophisticated surveying instruments specifically, in the area of engineering surveys, have evolved. These instruments such as the handheld Global Positioning System (GPS), Reflectorless TS, Remotely Robotic TS, DGPS, Smart station, and Laser Scanning Survey Instruments have significantly improved the capabilities and performance in terms of precision, accuracy and time expenditure of surveying instruments (Amezene and Bekele, 2012). There are many TS instruments in use today, most users purchase these instruments without fully comprehending the efficacy or reliability of these instruments. It is therefore important to evaluate their performance to recommend a better brand for control extension.

Many scholars have worked on the comparison of different TS instruments and other surveying instruments in executing some survey jobs. Notable among these researches are: Ameen et al., (2004) carried out research to evaluate the accuracy between RTK GPS and TS instrument in the adjustment of a closed Traverse. He computes the misclosure errors of easting and northing for both traverse of DGPS and total station. Two surveys were completed, one using a Nikon DTM821 TS instrument and the other using a Leica SR530 RTK field Unit and Base station with a radio link. The aim was basically to compare the resulting coordinates obtained from the RTK survey to those derived from the TS survey.

Gidado et al. (2022) made a Comparative analysis of TS instrument and a Spirit Level in Generating a Digital Terrain Model. They concluded that the total station has an advantage over the spirit level. The TS instrument is faster in data capture, shorter time and safer means of data processing and has the ability for data storage and retrieval electronically, and the telescope can be tilted to sight a point that the spirit level lacks. Eze et al. (2022) investigated the relative accuracy of selected Total Station instruments for a Closed Traverse Survey. The results indicate that all the TS instruments under study were very good for spatial data acquisition as they obtained the maximum angular and minimum linear accuracies for a third-order control survey. Matthew (2019) compared the robotic TS instrument reflector-less measurement and terrestrial laser scanning for building modelling. In his research, It was found that there was an average difference between the two models in easting of 9.8mm, northing of 10.4mm and elevation of 10.7mm. The distance difference between the two models was calculated to be 17.9mm. Also, Alade (2018) in his study investigated the potential for the use of three different types of total stations namely Leica TCA2003, Leica TS30 and Trimble S6 for structural deformation monitoring. Static test trials were carried out by simulating a dam around the Nottingham Geospatial Building (NGB) at the University of Nottingham Jubilee Campus. The results were then compared in terms of the actual accuracies obtainable, precision of measurement as well as speed of monitoring. He concluded that TS30 and S6 can make precise and accurate measurements.

Although, many authors had worked on the comparison of different TS instrument and also on TS instrument with other instruments, but has not touch on the comparison in terms of performance of these brands of TS instrument in control extension. It this study, four different models of TS instruments of similar specification from different manufacturers were compared. This was achieved through the establishment of four corner control points in a closed loop traverse survey with a very precise Leica 1201+ Series TS instrument. The coordinates obtained with the Leica 1201+ Series TS instrument serves as the reference coordinate points for the purpose of comparison with other four. A closed loop traverse was similarly carried out on these already established reference control points with each of the four different models of TS instrument. The outcome of the results from the four TS instruments was evaluated, analysed and compared to know their performance in terms of accuracy and precision. The study also determines whether the result from these four TS instruments is significantly different from each other or not in control extension.

Study Area

The study area is Modibbo Adama University Yola, located at Sangere in Girei LGA, of Adamawa State Nigeria. The University lies between latitude $9^0$20'30" N and $9^0$21’05”N and longitude $12^0$29’48”E and $12^0$30’25”E. It has a spatial extent of about 5119.79 hectares (51.20 km^2).

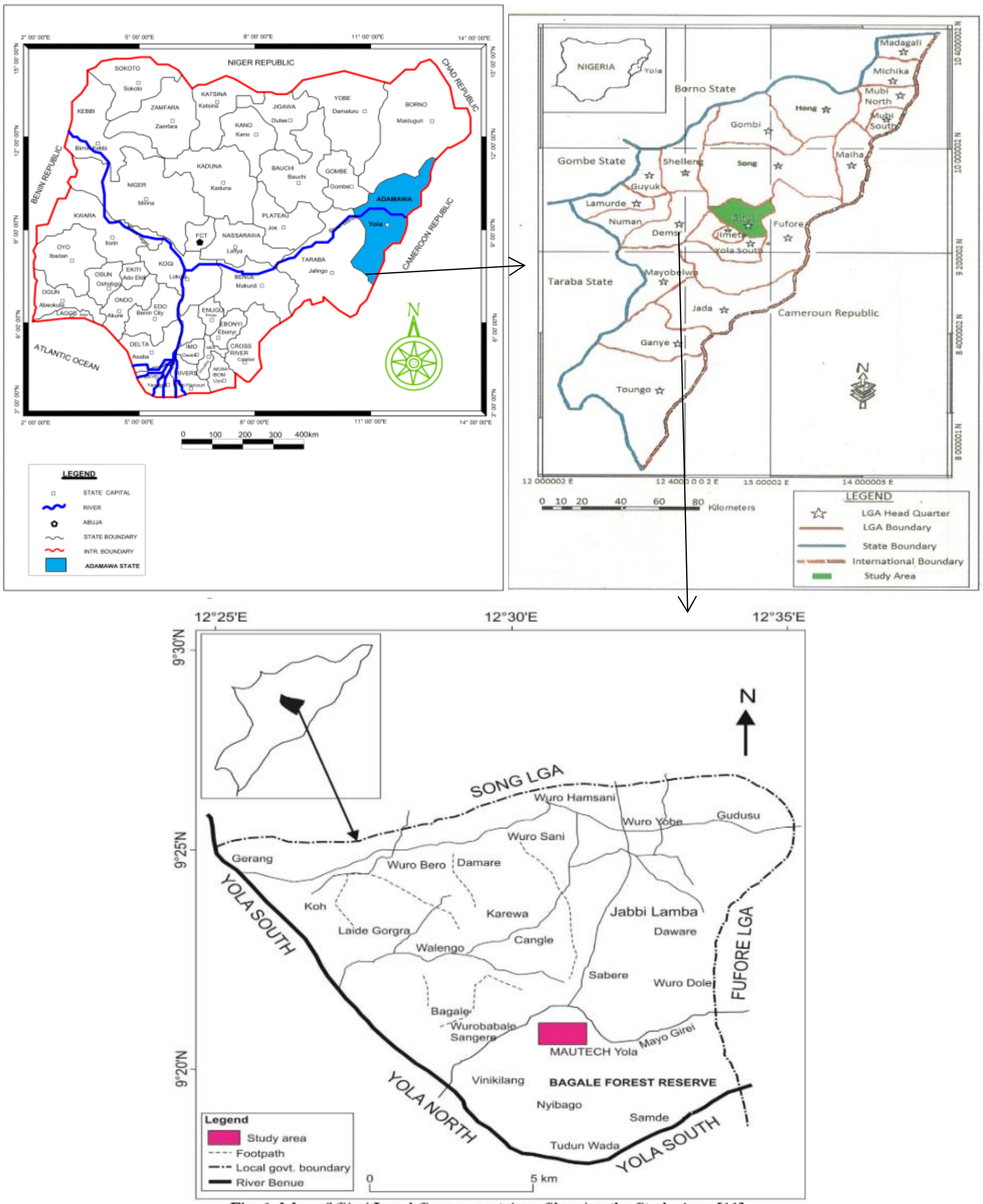

Fig. 1. Map of Girei Local Government Area Showing the Study Area [11].

Figure 1: Study Area
Source: Vahyala et al. (2018) and NASRDA (2011)

MATERIALS AND METHODS

Materials used

i. Four different models of Total Station Instruments with their associated accessories namely: Ruide RTS-820 Series, Nikon TS DTM-352/332, Sokkia CX – 105 series, and Topcon Total Station GTW-210 Series with Leica 1201+ Series for RF
ii. Microsoft Word, Excel, AutoCAD 2009 and Matlab 8.4 R2014b software.

Methodology

The methodology adopted in this research is divided into; data acquisition, data processing, and adjustment of the processed coordinates.

Data Acquisition

Office and field reconnaissance were first carried out. During the reconnaissance survey, some existing coordinate points were found near the study area. The coordinates were established in the area for the purpose of connecting survey work in the university. These existing coordinate points were used for the control extension in this study. The coordinates are shown below in table 1

Table 1: Existing Horizontal Coordinates

STATION	EASTHINGS (mE)	NORTHINGS (mN)
MG01	224063.6496	1033148.0598
MG07	224192.2392	1033260.0456
MG06	224027.3807	1033350.6224

Before the acquisition of data by the TS instruments, the calibration status of the instrument was first checked. It was discovered that, the instrument were calibrated during a routine check on the instruments. On each of the instruments, the date for the calibration was indicated. The date was less than a month to the time the data for this research was acquired.

Although, the instruments were said to have been calibrated, but a quick check was carried out to be sure that the calibration status of the instruments are still intact. To carry out the check, the TS instruments were used to measure the coordinates of the existing control points near the research site shown in table 1. The control points used for the check were MG01 and MG07 with coordinates 224063.6496mE, 1033148.0598mN and 224192.2392mE, 1033260.0456mN respectively. The TS instruments were placed on MG01 to determine the coordinates of MG07 one after the other. The coordinates determined by the TS instrument were compared with the existing coordinates. It was discovered that the highest difference in coordinates was found to be 0.00231mE with Sokkia CX 210/310 and 0.00303mN with Topcon GTW-210. With this result, it became clear that, all the TS instruments calibration status are intact and therefore good to be used for the data acquisition.

For a better result that will be free from any atmospheric influence, the survey was deliberately done during morning time. This choice of time of the day was to avoid error due to high temperature sunshine. The Leica 1201 + Series Total Station Instrument was first used to extend controls in a closed loop traversing survey. Repeated measurement and observation of distances and angles were taken for five days. The complete network of measurement and observation of angles and distances was performed three (3) times each day. The average values of the angles and distances were then used in the computations of preliminary horizontal coordinates using the observation equation method of least square adjustment in a MATLAB 8.4

R2014b software.

Similarly a closed–loop traverse was carried out with each of the four (4) TS instruments (Ruide RTS – 820 Series, Sokkia CX 210/310 series, Topcon GTW-210 Series, Nikon TS DTM-352/332). Measurement and observation of distances and angles were taken in clockwise direction. The observed angles and distances were then used in the computations of preliminary horizontal coordinates which were later adjusted. The step by step survey with the TS instruments is as follows: The survey started from the existing connecting control point MG01. The TS instrument was mounted on a tripod and stuck into the ground. The instrument was setup over the ground control point MG01. Temporary adjustment which involves; centering, levelling and focusing was performed. The measurement was carried out using the angle and distance mode observations. The procedure involves bisecting the reflector which was mounted on the connecting control point MG07 on face left. The TS instrument was later turned to the reflector mounted on the first unknown point, NJ02. Still on the same face, the horizontal angular readings were recorded. The TS instrument was then transited on the face right and the horizontal angle and distance readings of the foresight and back sight were taken and saved. The same observation procedure continued until all points were traversed in a closed loop, closing on the starting control point MG01. The angles obtained were reduced to get average mean horizontal angles and distances between stations. The average horizontal angles and mean distances were used alongside with the connecting coordinate of control point to compute the preliminary coordinates of the unknown points. The data obtained were then processed to obtain the final coordinates of points.

Data Processing Procedure

The data acquired from the total station observations were downloaded into a computer system folder. The total station data (angles, distances, and northings and eastings) were formatted in a Microsoft Excel 2007 spreadsheet and saved in a folder.

Adjustment of the Processed Coordinates

The method of observation equations of the least squares adjustment where the number of equations formed is equal to the number of observations was adopted in adjustment of these observed data. The mathematical formulation of this procedure is as follows:

Given $L = f(x)$, then $L_a = f(x_a)$ (1)

Where; L is the elements of observation

x is the corrections vector

x_a is the adjusted parameters

But $L_a = L_b + v$ and $x + x_o$, substituting $x_a = x + x_o$ from the above equation

$L_b + v = f(x + x_o)$ (2)

Where; v is the residual vectors

Linearizing by Taylor's series expansion, $L_b + v = f(x_o) + X\frac{\partial F(x_o)}{\partial x_o}$

$L_b + v = f(x_o) + Ax$

Where; A is the design matrix

And $A = \frac{\partial F(x_o)}{\partial x_o}$

If $f(x_o)$ L_o then $L_b + v = Ax + L_o$

$V = Ax + (L_o - L_b)$ but $L_o - L_b = w$

$V = Ax + w$ general observation model.

Then $\emptyset = PV^2 = V^TPV$ = minimum

Where P is the weight matrix

$V^TPV = (Ax + w)^TP(Ax + w) = (A^Tx^T + w^T)\,P\,(Ax + w) = A^Tx^TPAx + \{\,x^TA^T\,Pw + w^TPAx\,\} + w^T\,Pw = A^Tx^TPAx + 2x^TA^TPw + w^TPw$

$\sigma\emptyset = \frac{\partial(V^TPV)}{\partial X^T} = 2A\,PAx + 2A\,Pw = 0$

$x = -(A^TPA)^{-1}\,(A^TPw)$

$x = -M^{-1}U$ (3)

Where $M = (A^TPA)^{-1}$ and $N = (A^TPw)$.

A Computer program was written and developed that serves all the Total stations in MATLAB 8.4 R2014b for the adjustment and computations. The coordinates of the reference network were considered as 'true' RF which was determined in mm level. The RMSE was computed using the following formula:

RMS = $\sqrt{\Sigma}\,\frac{L-l2}{n-1}$ (4)

Where: L is the established value, l is individual measurement and n is the number of measurements.

The precision of observed or measured data is determined by computing its Standard deviation; which is a measure of variations of the repeated measurement, i.e. the precision of each observation. It can be computed from the mean values of the individual measurement. The Standard deviation (SD) is computed using the following formula:

$$SD(L) = \sqrt{\sum_{i=1}^{n} \frac{(L-l)2}{n-1}} \quad (5)$$

$$L = \sum_{1}^{n} Li/n \quad (6)$$

Where: L is the true or established value, Li is the individual measurement, L is the mean value of the measurements and n is the number of measurements.

A chi- square statistical test on the computed adjusted coordinates variances on all the five TS instrument were carried out to see if the procedure had distorted any of the adjustment procedure.

The relationship for the chi-square test is depicted as follows:

H_0: $V^TPV = \sigma_{02}$(V^TPV is within the confidence limit which will be accepted) 7

H_1: $V^TPV = \sigma_0^2$(V^TPV is not within the confidence limit which will be rejected) 8

The level of significance chosen is 0.01 ($\alpha = 0.01$)

The statistics for testing is $\chi^2_{1-\alpha/2}\, df < V^TPV < \chi^2_{\alpha/2} df$ (9)

Where $\alpha/2 = 0.005$ and $1 - \alpha/2 = 0.995$

A Two-way NOVA statistical analysis was carried out on the mean adjusted observations of the TS instruments to determine whether there is any significance difference between these models and also if these measurements and observations made are either affected by the instrument type or by the weather condition at 0.01 level of significance.

The two-way ANOVA has the following relationship:

The two hypotheses are

$H_{01}: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ (10)

(i.e there is no row effect or the mean of rows are equal)

H_1 : At least one α_i is not equal to zero (i.e row effect)

$H_{02}: ꞵ_1 = ꞵ_2 = ꞵ_3 = ꞵ_4 = 0$ (11)

(i.e there is no column effect or column means are equal)

H_2: At least one $ꞵ_i$ is not zero

$\alpha = 0.01$ was chosen as the Level of significance

The sum of Squares for the row means (SSRM)

$SSRM = \sum_{i=1}^{r} T_i^2/c - T^2/rc$ (12)

$S_1^2 = SSRM/r\text{-}1$ (13)

The sum of squares for column means (SSCM)

$SSCM = \sum_{j=1}^{r} T_i^2/r - T^2/rc$ (14)

$S^2_2 = SSCM/C\text{-}1$ (15)

Error Sum of Squares (ESS), but first TSS is computed as follows:

$TSS = \sum_{i=c}^{r} \sum_{j=1}^{c} X_{ij}^2 - T^2/rc$ (16)

$ESS = TSS – SSRM – SSCM$ (17)

$S^2_3 = ESS/(r\text{-}1)(c\text{-}1)$ (18)

$F_1 = S_1^2/S^2_2$ (19)

$F_2 = S_2^2/S^2_3$ (20)

The least squares adjustment of the total station observations was carried out using Matlab 8.4 R2014b software to determine the reliability of the adjusted observations and those of the adjusted parameters. The total station observations were adjusted using least squares adjustment procedure stated above in a MATLAB depicted program. The design matrix (A), observation matrix (L), weight matrix (W), and matrix of unknown (X) of the adjusted TS observations (distances and azimuths) were respectively 8 x 6, 8 x 1, 8 x 8 and 8 x 1 matrices.

The MATLAB program code is as follows:

1. Launching of The Matlab Application Package.
2. Importation of all the Design Matrices (A,L. & W) Into The Matlab Coding Environment.
3. Coding and implementing the OBSERVATION EQUATION MODEL (L = F(X)).consisting of the following :
   i. Computing the Correction vector ($x = [A^{`}A]^{-1}[A^{`}L)$
      x1= (inv(A'*W*A))*(A'*W*L) for weighted observation &
      x11=(inv(A'*A))*(A'*L) for Un-weighted observations for all the equipment used. Thereafter,
   ii. Computing the Adjusted Parameters ($X^a = X^O + x$)
      X1adj = TS Appr + x1 for weighted parameters &
      X11adj = TS Appr + x11 for Un-weighted observations for all the equipment used.
   iii. Computing the Vector of Residuals (V = Ax + L). i.e from TS
      VI = (A*x1)+L for weighted Observations &
      VII= (A+x11)+L for Un-weighted observations for all the equipment used.
   iv. Computing the Adjusted Observation ($L^a = L^O + V$) i.e. from TS
      Ladj1 = Lappr+V1 for weighted Observations &
      Ladj11 = Lappr+V11 for Un-weighted observations for all the equipment used.
   v. Computing the A- posterior Variances (i.e from TS)
      Apost1=(V1'*W*V1)/ (n-m)for weighted Observations &
      Apost11=(V11'*V11)/ (n-m)for Un-weighted observations for all the equipment used.

RESULTS AND DISCUSSION

Results

The results of this research are presented in various formats

Table 2: Sample of observed angles and distances with Leica TS

STATIONS	Sight at	Angles			Distances (Meters)
		Deg.	Min.	Sec.	
MG01	NG02	22	35	15.36	345.6512
NG02	NG03	313	22	06.60	246.1386
NG03	NG04	226	50	10.86	350.7522
NG04	MG01	314	12	35.18	248.7885

Table 3: Final Adjusted Coordinate Results from the Four Models of Total Station

ST.	SOKKIA TS		RUIDE TS		TOPCON		NIKON	
	E	N	E	N	E	N	E	N
MJ01	224063.6497	1033148.0598	224063.6496	1033148.0598	224063.6496	1033148.0598	224063.6496	1033148.0598
NJ02	224408.2032	1033120.0650	224408.2062	1033120.0650	224408.2040	1033120.0640	224408.2045	1033120.0650
NJ03	224225.2109	1032955.3780	224225.2194	1032955.3800	224225.2139	1032955.3780	224225.2130	1032955.3770
NJ04	223875.7126	1032985.0250	223875.7130	1032985.0240	223875.7113	1032985.0220	223875.7133	1032985.0240

Table 4: Difference in area of the Traverse

	SOKKIA TS	RUIDE TS	TOPCON TS	NIKON TS	REFERENCE TS
Areas	62209.517 m^2	62209.621 m^2	62209.690m^2	62209.478 m^2	62209.531 m^2
Difference with the Ref. TS	0.014 m^2	0.09 m^2	0.159 m^2	0.053 m^2	

Table 5: SD values in Northings and Eastings of the four TS instruments

Station/points	SOKKIA TS		RUIDE TS		TOPCON TS		NIKON TS	
	∂E	∂N	∂E	∂N	∂E	∂N	∂E	∂N
MJ01								
NJ02	0.00128	0.006643	0.0057240	0.0025569	0.000519	0.0023971	0.0010677	0.0020229
NJ03	0.00012	0.001066	0.0137508	0.0022874	0.003451	0.0010937	0.0031496	0.0028382
NJ04	0.00298	0.002988	0.0020847	0.0017339	0.000907	0.0007149	0.0013052	0.004240

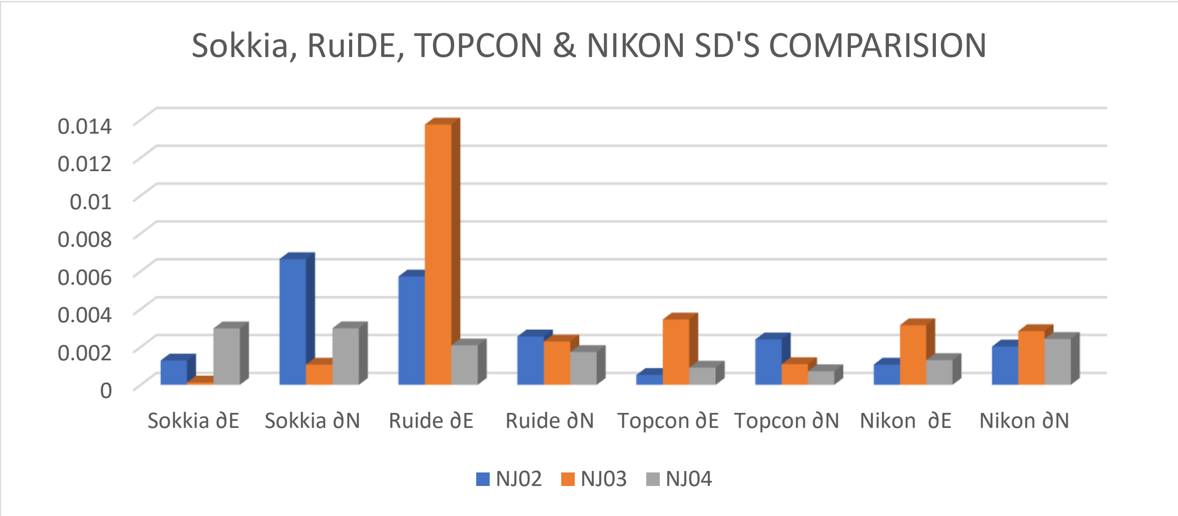

Figure 2: SD values of Sokkia TS, Ruide TS, Topcon TS and Nikon TS

Table 6: RMSE values in Northings and Eastings of the TS instruments

Station/Points	SOKKIA TS		RUIDE TS		TOPCON TS		NIKON TS	
	(E)	(N)	(E)	(N)	(E)	(N)	(E)	(N)
MJ01								
NJ02	0.001847	0.003797	0.005702	0.0034381	0.001285	0.0044608	0.0020398	0.0038481
NJ03	0.004150	0.001432	0.012663	0.0035036	0.006251	0.0025988	0.0052185	0.0045962
NJ04	0.002942	0.004273	0.001525	0.0015142	0.002799	0.0013434	0.0016117	0.0033859

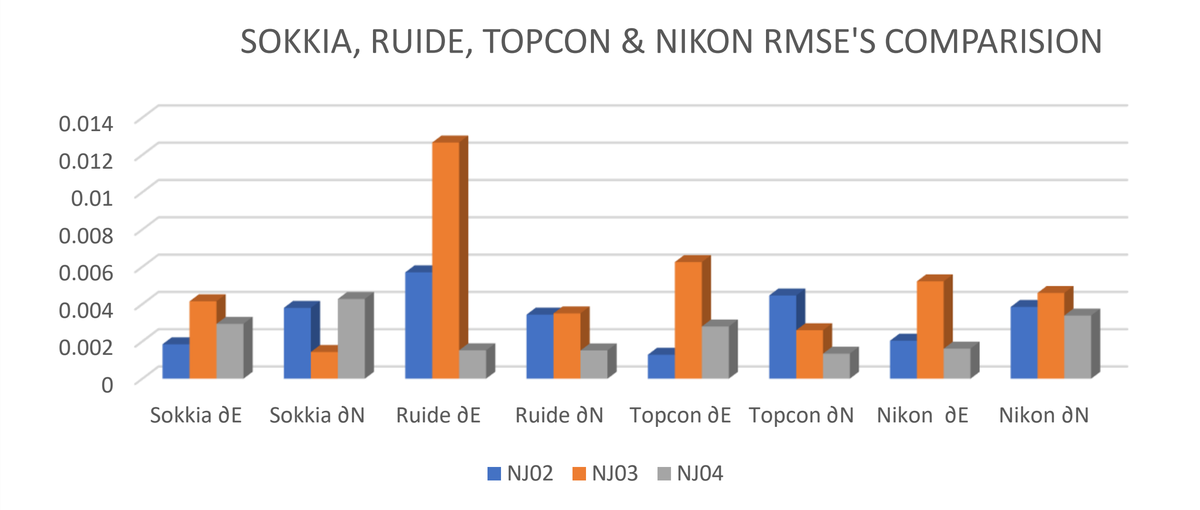

Figure 3: RMSE values of Sokkia TS, Ruide TS, Topcon TS and Nikon TS

Discussion

A chi-square statistical test was carried out on the computed adjusted coordinate variances of all the five TS instrument results. The result points out that at a 0.01 level of significance, the process did not distort any of the adjustment procedures. The root mean square error (RMSE) and standard deviation (SD) were also computed to evaluate the accuracy and precision of the repeated mean of the adjusted final coordinates for all the four TS models as shown in table 5 and 6. In addition, the bar charts in Figures 2 and 3 further demonstrate the results in bars. It was observed that in precision, the coordinates measured, computed and adjusted are indeed very precise such that the only SD value seen to be far away from others is 0.0137508m. Furthermore, the values of the four TS are indeed close to the true value (the Leica TS). This is drawn from the RMSE value which has the highest value of 0.012663m.The final mean adjusted coordinates are presented in table 3 for all the TS models.

A Two-way ANOVA statistical analysis on the mean adjusted observations of the TS models was carried out to determine if there is any significant difference between the results of these models and also if these measurements and observations made are affected by the instrument type or by the weather condition at 0.01 level of significance. The lowest p value for the two-way ANOVA was found to be 0.15, which shows that the TS instrument type or model had no effect on the large part of the data gathered, and also that all the TS used are not significantly different from one another at 0.01 level of significance. The difference in the data is as a result of the weather conditions.

CONCLUSION

The total station (TS) instrument is one of the many instruments used to perform many tasks in the field of geodesy, engineering surveys, and architectural and mining surveys with different precision and accuracy level conditions on the needed requirements. This research study was to evaluate and compare the performance of four different brands of total station instruments in terms of their accuracy and precision in a horizontal control extension survey. Specifically, a comparison was made between Sokkia CX-105 series TS, Topcon GTW-210 series TS, Nikon DTM-352/332 series TS and Ruide RTS-820 series TS against the Leica 1201 + Series TS which was used to determine the reference coordinate. The result of the reference coordinates was compared against each of the other four TS instruments to determine how precise and accurate they with reference to the reference coordinates established with the Leica 1201 + series.

The coordinates obtained with all the TS models were compared with that of the reference coordinates. From the statistical evidence, the result from the four brands of the four TS shows that there was no significant difference in all the coordinates with the reference TS instrument. A Standard Deviation (SD) was used to examine the precision, while Root Mean Square (RMS) was used to express how close the results of the four TS are to the reference coordinate that is the accuracy. From the results of the SD and RMS, it was realized that the coordinates from the four TS were accurate and precise when compared to the reference coordinates. The Two-way ANOVA test carried out also concludes that largely the TS instruments type used did not affect the measurement gathered at 0.01 level of significance.

Therefore, it could be concluded that all the TS instruments are indeed accurate and precise, and the observations are not significantly different from each other. Therefore, any of the four total stations can be used for horizontal control extension surveys especially in a small and medium control extension project.

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