Application for Automatic Estimation of Instrument Constant and Comparative Analyses of Linear Accuracy of Different Total Station Instruments

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The research aims is to develop a graphical user interface for automatic estimation of instrument constant using MATLAB programme and compare the linear accuracy of three total station theodolites relative to instrument constant. A baseline of 900m was divided into three arc nodes with four node points. Total Station was used for the baseline alignment and repeated linear distance measurement of the arc segment was made. Most probable values were calculated while final matrix of adjusted observations and residuals of each observation were obtained from the GUI. The instrument constants (k) determined using least square adjustment for Stonex R2-5 PLUS, South NTS-350 and Trimble M3 were +0.072mm, +0.028mm and +0.086mm respectively. A two-tailed student t-test and f-test at α = 95% confidence level were used to test the mean and variance of the adjusted observations. The student t- test results revealed no significant difference between the means of the linear data. Also, there was no significant difference between the variance of the instrument's linear data for the f- test. It was discovered that the instruments used in this research possess reasonable linear accuracy and their residuals are quite within the bounds of accuracy. South instrument is rated the best among the three instruments, followed by Trimble and Stonex total station instrument respectively with respect to the instrument constants (k).The established baseline should be checked yearly to support better monitoring and stability of the beacons before instrument standardization. Surveyors are advised to calibrate their instruments using the established baseline.

Keywords*:* Instrument constant, Most Probable value, Graphical User Interface, Least Square Adjustment, Residual

Introduction

Large percentage of Electronic Distance Meter (EDM) devices currently produced are integrated into total stations to provide potential for angular and distance measurement as well as coordinate computation. Sizable number in EDM technology are "reflector less" units which measure distance without using prisms to about one kilometre under a favourable weather condition. It can be classified as being based on either a time-of-flight (TOF) or a phase shift measurement (Bayoud, 2006).

Linear observation data derived from EDM or other sources are used to create vectors, coordinates, elevations, areas, volumes, plans and maps. Measurements are often split into horizontal and vertical components to simplify calculation. The precision values specified by the electromagnetic distance measurements manufacturing companies can lose their correctness over time. So, it is imperative to control the EDM instrument over time intervals in established EDM calibration baselines created specifically for the purpose. The effects of errors in measured distance can be significantly minimized by calibrating EDM equipment, using consistent methods and good network design. Repeated measurements can be averaged and any outlier measurements discarded. Independent checks like measuring a point from two or more locations or using two different methods may be employed and errors can be detected by comparing the results of the two measurements.

Generally, the standardization of electronic distance measuring instruments involves the determination of instrument constants, scale factor, cyclic error on most bases and the assurance that the measured distances meet accuracy specifications in line with Erenoglu (2018) and Sprent and Zwart (1978). Index error, scale error and cyclic error constitute the systematic error associated with EDM equipment (Australian Capital City, 2014). In many countries, an accreditation certification will accompany every EDM equipment calibrated or used in modern infrastructure construction sites by law (International Federation of Surveyors, 2015).All surveying instruments and their measurements suffer from errors (Bannister & Raymond, 1979). To refine the measurement results, it is necessary to use procedures restricting influence of the instrument errors on the measured values, implement numerical corrections, determine the magnitude of the errors and compute the standard deviations of measurements of distance meters of total stations EDM from least squares. It is with this in view that this research designed a standardized base within the Federal University of Technology Akure for calibrating Electronic Distance Measuring instruments which will also be useful to surveyors within Ondo State.

Objectives targeted at achieving the aim in this research includes developing a Graphical User Interface (GUI) for automatic estimation of instrument constant using MATLAB programme and comparing the linear accuracy of three total station theodolites relative to instrument constant.

Materials and Methods

The set of physical substance and rules used in this research are discussed in this section.

Materials

Total Station (South NTS 350), Total Station (Stonex R2-5 PLUS 350), Total Station (Tremble M3) and Theodolite (STT2 PlusStonex) with all accessories peculiar with each instrument were the surveying equipment used in the study. MATLAB Software R2012a was deployed for data processing and visualization while Microsoft Office Excel was used for analysis of the results.

Study Area

The study area chosen for this study is the South-West part of Obanla area, Federal University of Technology Akure, Ondo State. It is located geographically in UTM between 806800mN 735400mEand 807200mN 736300mE.The studysite is situated along the road linking the New Post-Graduate Hostel to Obakekere – Obanla main Road (Figure 1).

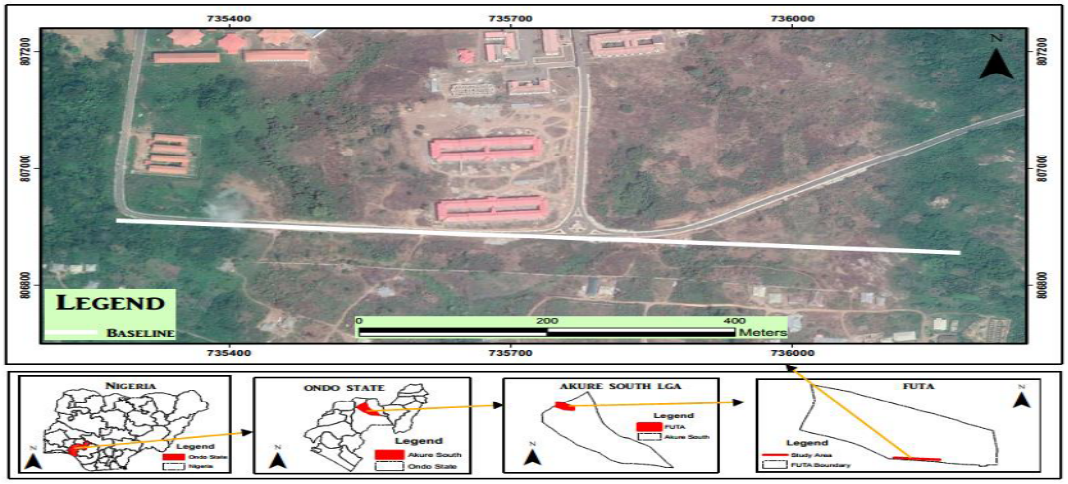

Figure 1: The Study Area

Methods

A baseline length of 900m was adopted in this study. The baseline was divided into three arc nodes with four node points in line with National Geodetic Survey. Each point was aligned using the first point marked "1". Other inter distances were marked as '2', '3' and '4' respectively, ensuring that the sum of all the distances equals the total length of the baseline.

The primary data used in this research were field measurements obtained from the three Total Station instruments. However, prior to field observation, the total station was set up firmly on the first monument, temporary adjustment which involve centring, levelling and focusing were performed. The observational procedure for South NTS 350, Stonex R2-5 PLUS 350 and Tremble M3 were similar. Data acquisition was executed by setting on node points (monuments) while observing each arc (segments) sequentially using the three Total Stations on three different days. Each line segment was measured ten times and the Most Probable Value (MPV) computed. The data recorded were pre-processed according to the uniqueness and common characteristics in sequential order of observation in MS Excel format shown in Table 1.

Table 1: Data from the three total station instruments

LINE	OBSERVED DISTANCES (south)	OBSERVED DISTANCES (stonex)	OBSERVED DISTANCES (tremble)
1 – 2	451.255	451.222	451.281
1 – 3	722.055	722.057	722.116
1 – 4	903.228	903.298	903.357
2 – 1	451.256	451.225	451.284
2 – 3	271.041	271.023	271.082
2 – 4	452.321	452.319	452.378
3 – 1	722.175	722.045	722.104
3 – 2	271.031	271.028	271.087
3 – 4	181.173	181.154	181.213
4 – 1	903.353	903.314	903.373
4 – 2	452.348	452.335	452.394
4 – 3	181.178	181.161	181.220

Automatic Estimation of Instrument Constant

MATLAB programming language was used to design the algorithm, model,and code. It was also used to produce the Graphical User Interface (GUI) for estimation of instrument constant. Specifically, the observation equation method of least square adjustment computation as presented in Equation (1) was adopted to compute the field data acquired in this study.

$$V = AX - L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$X = (A^T PA)^{-1}(A^T PL) \ldots\ldots\ldots \quad (2)$$

(Rainsford, 1968)

Where:
V = Residuals
L = Observed Distance or Measured distance
X = Vector of Adjusted Parameters
A = Design Matrix (A- Matrix)
P = Weight Matrix

The GUI (Figure 2) was developed with MathWorks which helped in producing a final executable application that is installable on any computer without a need for MATLAB installation. The program was tested and debugged before use.

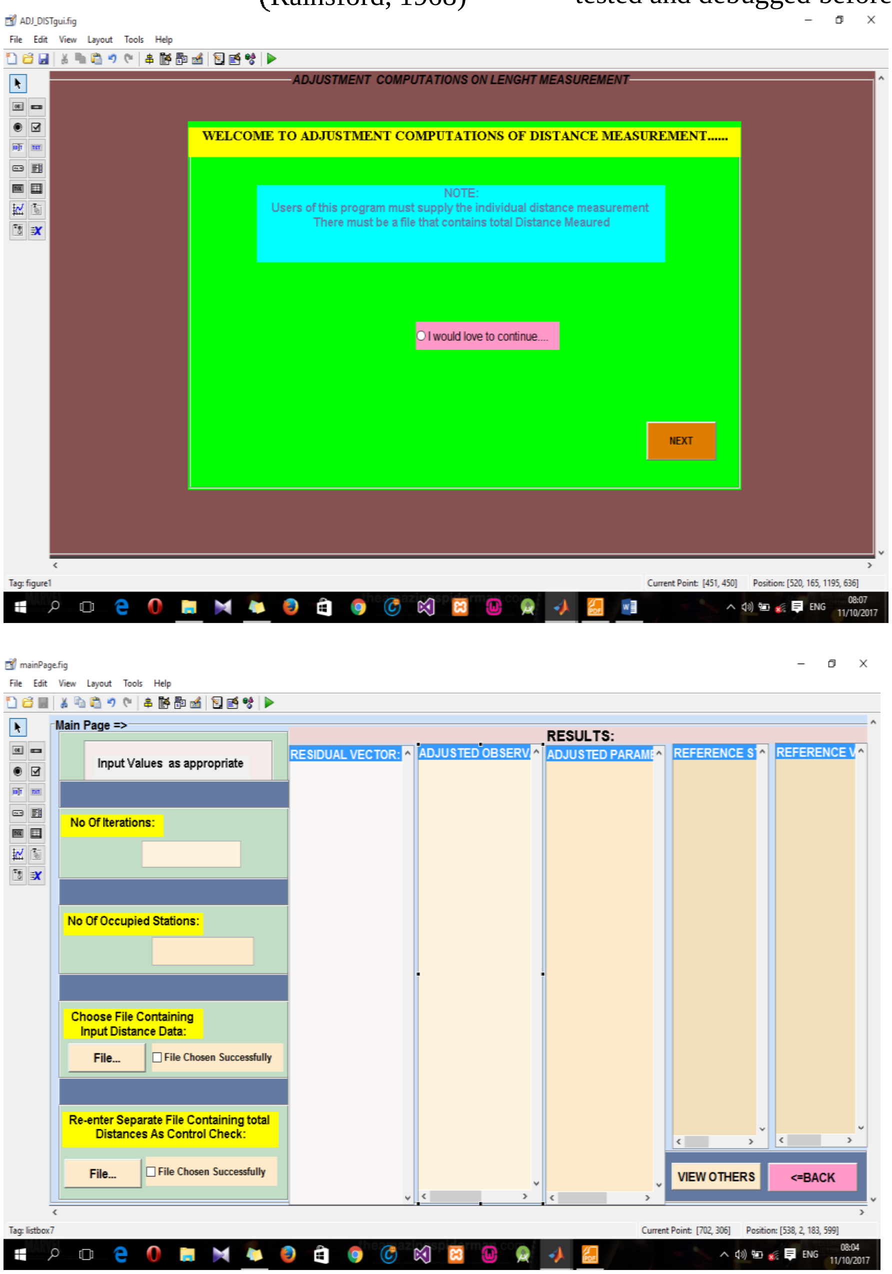

Figure 2: Graphical User Interface (GUI) of the MATLAB Program

Results and Discussion

The various tests conducted in this study to assess the linear accuracy of the three Total stations (Stonex R2-5 PLUS, South NTS-350 and Trimble M3) revealed striking characteristics about the datasets from the entire instruments. The instrument constants (k) determined using least square adjustment method for Stonex R2-5 PLUS, South NTS-350 and Trimble M3 were +0.072mm, +0.028m and +0.086mm respectively (Tables 2- 4). Notably too, the three Total Stations are precise in terms of their performance by repeatedly displaying similar measured values in line with Longley *et al*. (2011).

Table 2: Results of Stonex R2-5 Plus Total Station

STATION	INITIAL OBSERVATION (L)	ADJUSTED OBSERVATION (X)	RESIDUALS (V)
1 – 2	451.222	451.1605	-0.0615
2 – 3	271.023	271.0255	0.0025
1 – 3	722.057	722.114	0.057
2 – 1	451.225	451.1605	-0.0645
3 – 2	271.028	271.0255	-0.0025
3 – 1	722.045	722.114	0.069
2 – 3	271.023	271.0255	0.0025
3 – 4	181.154	181.2205	0.0665
2 – 4	452.319	452.174	0.035
3 – 2	271.028	271.0255	-0.0025
4 – 3	181.161	181.2205	0.0595
4 – 2	452.335	452.174	-0.161

X1 = 451.0885; X2 = 270.9535X3 = 181.1485; Instrument constant (k) = +0.072mm

Table 3: Results of South Nts-350 Total Station Observation

STATION	INITIAL OBSERVATION (L)	ADJUSTED OBSERVATION (X)	RESIDUALS (V)
1 – 2	451.255	451.181	-0.074
2 – 3	271.041	271.036	-0.005
1 – 3	722.055	722.189	0.135
2 – 1	451.256	451.181	-0.075
3 – 2	271.031	271.036	0.005
3 – 1	722.175	722.189	0.014
2 – 3	271.041	271.036	-0.005
3 – 4	181.173	181.250	0.077
2 – 4	452.321	452.258	-0.063
3 – 2	271.031	271.036	0.005
4 – 3	181.178	181.250	0.072
4 – 2	452.348	452.258	-0.087

X1 = 451.01535; X2 = 271.0085; X3 = 181.2225; Instrument constant (k) = +0.028mm

Table 4: Results of Trimble M3 Total Station Observation

STATION	INITIAL OBSERVATION (L)	ADJUSTED OBSERVATION (X)	RESIDUALS (V)
1 – 2	451.281	451.197	-0.084
2 – 3	271.082	271.085	0.0025
1 – 3	722.116	722.196	0.0795
2 – 1	451.284	451.197	-0.087
3 – 2	271.087	271.085	-0.0025
3 – 1	722.104	722.196	0.0915
2 – 3	271.082	271.085	0.0025
3 – 4	181.213	181.302	0.089
2 – 4	452.378	452.301	-0.0775
3 – 2	271.087	271.085	-0.0025
4 – 3	181.220	181.302	0.082
4 – 2	452.394	452.301	-0.0935

X1 = 451.111; X2 = 270.9985; X3 = 181.216; Instrument constant (k) = +0.086mm

The adjusted observations of the Three Instruments (Table 5) were analysed to determine which of the instrument was the best or if none was better than the other. The student t-distribution statistics (two tail student t - test to compare the means) and the F-distribution statistics to test whether two observed samples have the same variance was used for the analysis.

The hypotheses tested in this research for both 'means and variances' are:

H_0: $N_{ST} = N_{SO,}$ H_0 – There is no difference between Stonex linear data and South linear data.

H_0: $N_{ST} = N_{TR,}$ H_0 –There is no difference between Stonex linear data and Trimble linear data.

H_0: $N_{ST} = N_{SO,}$ H_0– There is no difference between South linear data and Trimble linear data.

The results obtained were subjected to further analysis by comparing the means and variances for any similarity or otherwise using a two-tailed student t-test and F-test at $\alpha = 0.05$ significant level to test the variance. For the t-distribution statistics, the result revealed that there was no significant difference between the means of Stonex linear data and South linear data because $T_{cal} = 0.0005050 < t_{tab} = 2.074$ therefore, there was enough evidence to accept the claim of null hypothesis and conclude that at least one mean is not significantly different from the other at 95% confidence level. Also, for the F-distribution statistics the result revealed that there was no significant difference between the variance of Stonex linear data and South linear data because $F_{cal}= 1.0002 < F_{tab}, = 3.53$ therefore, there was enough evidence to accept the claim of null hypothesis and conclude that at least one variance is not significantly different from the other at 95% confidence level.

Notably for t- distribution, the result between Stonex and Trimble data shows that there was no significant difference between their means because Tcal = $0.00092 < t_{tab} = 2.0739$, therefore, there was enough evidence to accept the claim of null hypothesis and conclude that at least one mean is not significantly different from the other at 95% confidence level. Similarly, F-distribution show no significant difference between the variance of Stonex linear data and Trimble linear data because $F_{cal} = 1.00002 < F_{tab}, = 3.53$ therefore, there was enough evidence to accept the claim of null hypothesis and conclude that at least one variance is not significantly different from the other at 95% confidence level.

Table 5: Results of Adjusted Data of the Three Instrument Used

STONEX DATA	SOUTH DATA	TRIMBLE DATA
451.1605	451.181	451.197
271.0255	271.036	271.085
722.114	722.189	722.196
451.1605	451.181	451.197
271.0255	271.036	271.085
722.114	722.189	722.196
271.0255	271.036	271.085
181.2205	181.250	181.302
452.174	452.258	452.301
271.0255	271.036	271.085
181.2205	181.250	181.302
452.174	452.258	452.301
TOTAL = 4697.44	TOTAL = 4697.90	TOTAL = 4698.31
MEAN (MST) = 391.456	MEAN (MSO)= 391.492	MEAN (MSO)= 391.526
VARIANCE (VST)= 34507.6348	VARIANCE (VSO) = 34515.7288	VARIANCE (VTR) = 34508.4336

Testing the difference between the means of South and Trimble linear data using a two tail student t – test also reveals that there was no significant difference between the means because T_{cal} = 0.001 <t_{tab} = 2.0739, therefore, there was enough evidence to accept the claim of null hypothesis and conclude that at least one mean is not significantly different from the other at 95% confidence level. Specifically, testing the difference between the variances of South and Trimble data indicates that Fcal =1.00021< = 3.53. Therefore, there was enough proof to accept the claim of null hypothesis and conclude that at least one variance is not significantly different from the other at 95% confidence level.

In the same vein, the residuals of Stonex R2-5 Plus, South NTS-350 and Trimble M3 instruments in Figure 3 shows that relative similarities exists between the three instruments. Also, South NTS-350 total station with constant (k) =+0.028mm indicates higher accuracy than Stonex R2-5 Plus 350 total station (constant (k) = +0.072mm) and Trimble M3 (constant (k) = +0.086mm). It was also observed that the three Total Stations are precise in terms of their performance by repeatedly displaying similar measured values in line with Longley *et al.* (2011).

Conclusion

The research reveals that the graph generated during the data analysis shows that all the instruments used in this research are of good linear accuracy. This is backed up with the student-t and f-distribution statistics which shows that the entire instruments residuals are relatively within the accuracy limits specified by the instrument manufacturer at 95% confidence interval. Also, the three instruments used for this research when compared reveals that none of the three instrument is better than the other. Specifically, SOUTH and STONEX gave 0.0005, STONEX and TRIMBLE returned 0.0009 while SOUTH and TRIMBLE gave 0.001. Therefore, SOUTH instrument is rated the best among the three instruments, followed by TRIMBLE instrument and STONEX Total Station Instrument respectively with respect to the instrument constants (k) obtained after least square adjustment. The software enhances checks on the linear accuracy of Total Station instruments to be automatically performed thereby leading to the determination of the instrument accuracy and calibration constant. The software can be adopted by state survey regulation agencies for determining the accuracy of survey instruments used by surveyors for performing linear measurement operations.

Recommendations

The research recommends that, the Graphic User Interface (GUI) developed using the MATLAB software in this research should be used for determining instrument constant of subsequent total stations. Also, the instrument constants obtained in the analysis of this study should always be used for observation correction whenever measurement is carried out using any of the instrument s listed. In addition, the baseline should be checked annually to enhance monitoring and stability of the pillars before instrument standardization. Geometrician of the future should test their measurements for compliance with these standards using least squares adjustment in MATLAB Programming language developed in this research

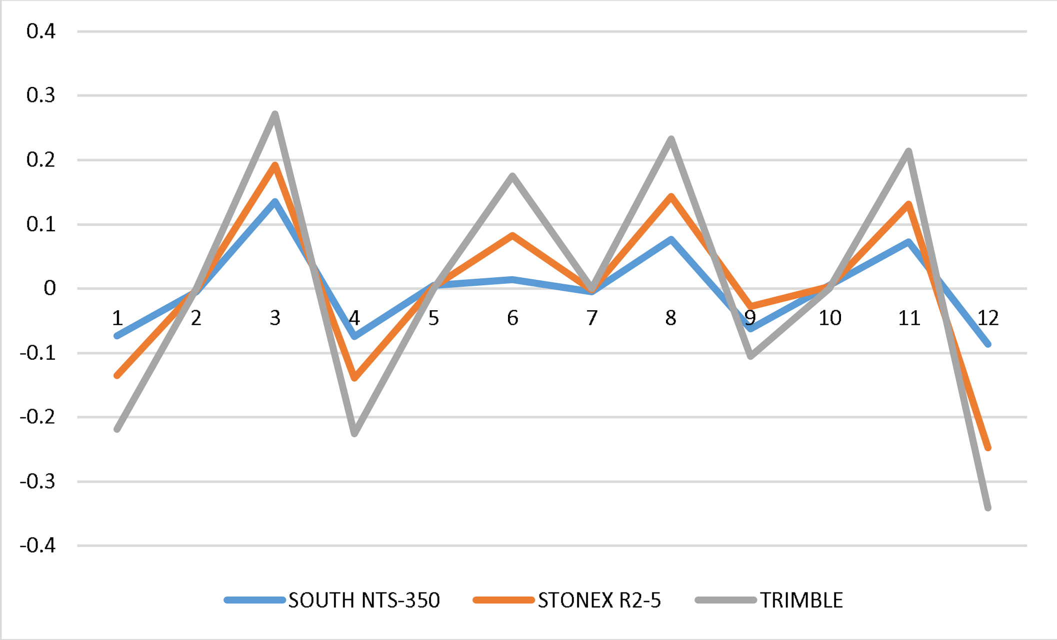

Figure 3: Residuals for the Total Station Instruments

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