# Establishment and Evaluation of Electronic Distance Measurement (EDM) Calibration Baseline

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Electromagnetic distance measurement (EDM) instrument requires a regular and proper calibration to determine the performance of the instrument and its standardization. This paper aims to describe the field procedures for the establishment of an EDM calibration baseline for distance measurements verification to cover the educational and research activities of the Federal university of Technology, Minna, Gidan-Kwano Campus. An outdoor calibration baseline in a straight line configuration was established for such purpose. The measurement of the baseline was performed using Leica TPS 1200 0.2 second (0.2") Total station. The calibration baseline was divided into four bays and a total number of two hundred (200) observations were done in combinations. The analysis of the obtained 200 sample data set yielded the most probable value for the four bays as; instrument constant K= -0.0047m. The standard error of the unknown parameter was determined as;$\sigma = \pm 0.00058$m. The analysis of the obtained 200 sample data set yielded the most probable value for the four bay; X1 =101.650m, X2 =199.7968m, X3 = 299.9189m, X4 =502.6423m. The result of the hypothesis testing reveals that $V^T$PV = 0.0028, at 95% significance ($\alpha$) level, with a degree of freedom of 195. The computed value for the chi square is given as; $\chi^2$ = 4.76980, the lower limit and upper limit as obtained from the statistical table is given as 0.052 and 6.23 respectively. The result of the hypothesis test indicate that the adjustment process was consistent and without distortion. It was concluded that the result obtained can reliably be used for the calibration of Electromagnetic Distance Measuring Equipment in Minna, Nigeria.

**Keywords:** Baseline Calibration, Electronic Distance Measurement Instrument (EDMI), Total Station, Least Squares

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## INTRODUCTION

With the introduction of electronic distance measuring instruments (EDMI) in the United States in 1952, the standardization problem was compounded since EDMI measurements are affected by meteorological conditions other than temperature and by several instrument uncertainties that require frequent periodic re-evaluations. Although the need for calibration base lines was evident, a test range specifically designed for EDMI re-evaluations was not available for more than a decade. Early in the 19th century, the Survey of the Coast, subsequently named the U.S. Coast and Geodetic Survey (USC&GS), now the National Geodetic Survey (NGS)] adopted the meter as the standard for use in geodetic surveys of the United States. Land surveyors, on the other hand, employed the foot as their standard, as did most surveyors involved in engineering and associated surveying activities. In 1963, USC&GS measured a multi-monumented line in Beltsville, Maryland, using high-precision taping techniques (Joseph *et al*., 2014). The distance of the Beltsville base was approximately 1,800 meters, different from the 1,650-metre distance normally utilized. Later, a much longer line (about 9,050 meters) near Culpeper, Virginia, was measured using similar procedures. Although no major restrictions were placed on the use of these base lines, few surveyors other than those from federal agencies used these facilities to calibrate their equipment (Joseph *et al*., 2014).

As more surveyors acquired EDMI, the surveying profession became concerned about the accuracy of their measurements. It has been shown that whereas accuracies attributed by the manufacturers to the instruments are reliable, errors in the observations, which are often systematic, can result from normal usage due to a reduction in the efficiency of electronic and mechanical components. Periodic maintenance, preferably by the manufacturer or a designated representative, is required to minimize such errors. It is equally important to verify the instrument constant and evaluate the measuring accuracy at more frequent intervals in conformity with International standard Organization (ISO 17123-4 -Optics and optical instruments, 2001).

The lack of EDM calibration Baseline in FUTMINNA posed a challenge to provide traceability of length for electro-optical equipment with; total stations, reflectorless total stations, laser scanners (Japhet *et al.,* 2021; Pagounis *et al*., 2022; Florian *et al.,* 2023). Hence, the aim of this research work is to highpoint the processes involved in the establishment of an Electromagnetic Distance Calibration baseline and the associated mathematical computation by method of least squares. The objectives of the study include;

1. Establishment of a calibration baseline subdivided into four bays marked with survey monuments.
2. Determination of angular and linear measurements on four (4) zeros on the established inter-pillar of the bays in combination.
3. Computation and evaluation of the acquired data using the least squares technique of adjustment.

## LITERATURE REVIEW

Electro-optical Distance Meter (EDM) calibration is the determination of instrument correction by comparing the value indicated by the measuring equipment with the known or true value. Due to the aging of the instrument, after repairs and services, jolts of the instrument would inculcate a lot of errors (Janssen, 2015; Japhet *et al*., 2022; Kinga *et al*., 2022; Pagounis *et al*., 2022; Florian *et al.,* 2023).

Zakar and Aliyu (2014) established a baseline using electronic distance measurement at the federal polytechnic Mubi to take care of some of the operations that may require the need for a Calibration baseline. This was achieved by taking thirty different measurements in their combination on the baseline. All measurements were corrected for meteorological and geometrical effects. The developed computer program using Fortran 77, based on the principles of least squares by method of observation equation reveals the computed result of the adjusted baseline to be; 1184.50027m, at a degree of freedom; 29 and the computed statistic $V^T$PV was also found to be 0.01554 at a level of significance (α ) of 0.5.

Karim *et al*. (2022) observed that Laser-based Electronic Distance Meters (EDMs) are used extensively to measure inner/outer dimensions in constructions and large volumes and needs to be calibrated regularly to assure its proper function. In their paper, a distance measurement system based on Opto-Electronic Oscillator (OEO) was used for EDM calibration. The calibration was performed in three steps; the first step was to construct a reference OEO system using off the-shelf optical telecommunication components. Then, the OEO system was used to calibrate an indoor baseline consisting of eleven distances ranging from 2.4 to 58 m. Finally, the calibrated baseline was used to calibrate the EDM.

One important perquisite for SI traceability is the correct estimate of the associated measurement uncertainty. To determine the magnitude of the errors and their statistical properties of distance measurements of EDM equipment, baselines (outdoor or laboratory based) are commonly used (Janssen, 2015; Florian *et al.,* 2023; Robert 2020; Japhet *et al.,* 2022; Kinga *et al*., 2022; Pagounis *et al*., 2022). However, establishing a direct link to the SI definition with low measurement uncertainty is laborious and hence, the need for calibration baseline for verification of distance meters on a regular check (following standards), further as legal metrological control of measurement or for error detection and more accurate results (Vsevolod *et al.,* 2022). This paper aims to describe a test field facility for distance measurements verification that has been established to cover the educational and research activities of the Federal University of Technology, Minna, Gidan-Kwano Campus.

## THE STUDY AREA

The Federal University of Technology, Minna, Gidan-Kwano Campus is located along Minna – Bida Road, in Bosso Local Government Area of Niger State, Nigeria.

Figure 1 depicts the FUTMinna Campus located at 09$^0$ 32’ 30.46”N, 06$^0$ 26’14.37”E at the top left, 09$^0$ 31’15.84”N, 06$^0$ 27’ 20.”67E at the bottom of the longitude and latitude respectively.

Figure 1: Map of Niger State showing Bosso LGA
Source: Department of Urban and Regional Planning, Federal University of Technology, Minna

Figure 2 depicts the Google image of the established EDM calibration baseline along a relatively flat terrain between the school workshop and the staff quarters at the main campus of FUTMINNA.

Figure 2: Established Calibration Baseline in FUTMINNA, Gidan-Kwano campus (2023)

## MATERIALS AND METHODS

Full determinations of the Instrument corrections (IC) Parameters were carried out for this study, as no existing calibration baselines was available for EDM checks. Checks were effected according to the manufacturer's manual and in accordance to survey the field procedures for EDMs (ISO 17123-4-Optics and optical instruments, 2001). The following checks: additive constant, scale error, cyclic error, thermometer and barometer checks, pointing error were carried out at the test field at Gidan Kwano Campus.

The test field consist of one marked instrument station (A) and three permanently mounted reflectors at typical distances for the usual working range of the particular EDM instrument (from 50m to 300m). The reference lengths of the lines were determined with a more accurate type of distance meter (Leica TS 1201). This testfield was established purposely for this research work on EDM checks and calibrations. Table 1 depicts the field observations of the straight-line calibration bay on the site carried out on 11/11/2020.

Table 3: Field observations

| Date of Observation | EDM Station order | X1 | Temp $0^c$ | Pressure Hpa | Relative Humidity |
|---|---|---|---|---|---|
| 11/11/2020 | A1 – A2 | 101.6501m | 29.3 | 1015.4 | 80% |
| 11/11/2020 | A2- A3 | 199.7967m | 29.3 | 1015.4 | 80% |
| 11/11/2020 | A3- A4 | 299.9189m | 29.3 | 1015.4 | 80% |
| 11/11/2020 | A1- A4 | 502.6423m | 29.3 | 1015.4 | 80% |

The first day's (11/11/2020) results gave the actual reference values and was recorded in a logbook for future reference. Analysis of the performance check are as follows: If the results from Check 2 indicate significant differences for all the checked distances, it is recommended that the check be repeated very carefully. If the second comparison check confirms the result of the first, a change in the instrument's performance (or instrument station) is suspected and it is necessary to find out the cause of the change before using that instrument for the project.

The next step was to determine the Additive Constant (a)

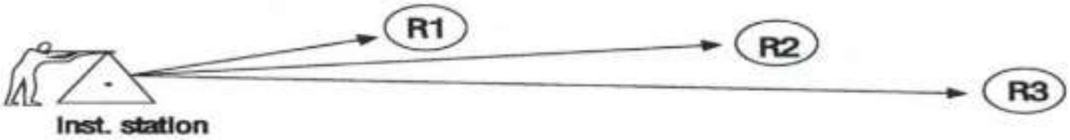

Figure 3: Performance Check on stability of the EDM at a Testfield at Gidan -Kwanu Campus

**Establishment of Calibration Baseline**

The field operation started with the concrete monumentation of the station mark using wild T2 theodolite and ranging poles to set out the calibration baseline. The EDM was set up on the starting point (A) and observations taking to the four bays established at varying lengths. This was followed by height measurement of EDM instrument and reflector's height using line tape and recorded in the field book. This was to determine the slope correction to bring the measured slope distance to horizontal distance. The reflector was sighted, and the centre of the prism was bisected, then the vertical and horizontal movement of the EDM was clamped. Checks for battery and signal were made by switching on the instruments on/off switch. The display showed 0000, indicating that the instrument was ready for operation.

Measurement was triggered by lightly touching "MEASURE" knob. The distance measurement was performed automatically within 5" (second), during this time, points were flashing at the digital display and finally the measured distance was displayed. The vertical angle reading was recorded from the EDM for slope correction. The atmospheric temperature was also recorded. Redundant measurements (200) were made in order to evaluate standard errors and establish probabilities. These redundant measurements were used to detect mistakes in the field work and to find an estimate for a true value by the principles of least squares.

When the slope distance L has been obtained from an EDM measurement, a slope correction must be applied to it in order to obtain the equivalent horizontal distance. Electromagnetic waves travel through the air with a velocity (V) and since by definition,

Distance (D) = $\frac{v \times t}{2}$

(i)

Where v is the velocity of the wave signal, t is the time of travel of the wave signal, and D is the measured distance. The unknown distance, D can be found by measuring the travel or transit time, t, if the velocity is known.

**Measurements of Inter-pillar Distances of the Bays in Combination**

Linear measurements of the various bays were taken in combination with the aid of the Leica TPS 1200 Total Station on a single reflector. The linear measurement was carried out in two phase the first phase in the morning and the later in the evening. This is to reduce the effect of refraction on the electromagnetic signal. The least squares observation equation was used, been the most rigorous method of adjustment which yields unbiased estimates for the parameters to be determined. Least squares adjustment is a statistical technique for carrying out objective quality control of measurements by processing set of redundant observations according to mathematically well-defined rules. The fundamental condition of least squares method is that the sum of the squares of the residual is a minimum. Thus, the least squares produce the most probable value (MPV) by simultaneously considering all factors and the same time making the sum of the square of the residual a minimum (Japhet *et al.,* 2022; Florian *et al.,* 2023).

**Computation and Evaluation of the Acquired Data using the Least Squares Technique**

Observation equations are sets of equations that show the functional relation between observed parameter and the adjusted parameter, the adjusted parameters to be determined are; $x_1,\ x_2,\ x_3,\ x_4$ and the instrument constant (k).

For each observation, an equation was set up expressing the relationship between the variation and the adopted parameters on one hand and the difference between the observed quantity and its corresponding computed values for the provisional distances on the other hand. The functional relationship between the measured distances and the unknown parameter can be expressed as;

$$x_1 + v_1 + k = 101.651\text{m}$$
$$x_1 + x_2 + v_2 + k = 301.442\text{m}$$
$$x_1 + x_2 + x_3 + v_3 + k = 601.365\text{m}$$
$$x_1 + x_2 + x_3 + x_4 + v_4 + k = 1104.017\text{m}$$
$$x_1 + v_5 + k = 101.65\text{m}$$
$$x_2 + v_6 + k = 199.796\text{m}$$

The design matrix (A), and the matrix of observation ( $L^b$ ) for the 200-sample size was developed from the parametric relationship as;

$$A=\begin{bmatrix}1&0&0&0&1\\1&1&0&0&1\\1&1&1&0&1\\1&1&1&1&1\\1&0&0&0&1\\0&1&0&0&1\\0&1&1&0&1\\0&1&1&1&1\end{bmatrix},\quad L^b=\begin{bmatrix}101.65\\301.442\\601.365\\1104.017\\101.653\\199.796\\499.714\\1002.353\end{bmatrix}$$

The generalized linear mathematical model of the least square observation equation is given by as; $L^b = f(X^a)$(Functional model of observation equation) (ii)

Where;

$L^b$ = Adjusted observation

$X^a$ = Unknown parameter

Each adjusted equation then becomes;

$$L^a = L^b + V \qquad \text{(iii)}$$

$L^b$ = =□observed parameters

V= residual

**The adjusted parameter**

$$\hat{X} = -\ (A^TPA)^{-1}A^TPL \qquad \text{(iv)}$$

$$V = A\hat{X} - L^b \qquad \text{(v)}$$

Where;

$\hat{X}$ = the adjusted parameter

V = vector of residual

A = design matrix

P = unit weight matrix

L= matrix of observation

**The a-posterior**

$$\sigma_0^2 = \left(\frac{A^TPA}{n-m}\right) \qquad \text{(vi)}$$

Where, n is the number of equation and m is the unknown parameter.

$$\sum\hat{X} = \sigma_0^2(A^TPA)^{-1} \qquad \text{(vii)}$$

## RESULTS AND DISCUSSION

The data used in this work were obtained from measurement carried out on the EDM calibration baseline. Two hundred (200) different measurements were carried out on the baseline. Due to the large sample size, Matrix Laboratory program (Mat LAB) was used to for the computation. The following results was obtained;

$$(A^TPA) = \begin{bmatrix}80&60&40&20&80\\60&120&80&40&120\\40&80&120&60&120\\20&40&60&80&80\\80&120&120&80&200\end{bmatrix}$$

; Where, $(A^TPA)$ is the coefficient matrix of the normal equation which is non-singular matrix,

$$(A^TPL^b) = \begin{bmatrix}0.00004217\\0.00007417\\0.00008620\\0.00006823\\0.000010831\end{bmatrix}$$

; $(A^TPL^b)$ is linear matrix ,

$$\hat{x} = \begin{bmatrix}101.6560\\199.7968\\299.918\\502.6423\\-0.0047\end{bmatrix}$$

; $\hat{x}$ *is* the matrix of the adjusted parameters which shows the most probable value of the various bays and the instrument constant (k)

And $\sigma_0^2$ = 0.000014359 is $\sigma_0^2$ is the a-posterior.

$$\sum\hat{x} = \begin{bmatrix}0.0000003446&-0.0000000862&0.0000000574&0.0000000574&-0.0000001436\\-0.0000000862&0.0000003446&-0.0000000862&0.0000000574&-0.0000001436\\0.0000000574&-0.0000000862&0.0000003446&-0.0000000862&-0.0000001436\\0.0000000574&0.0000000574&-0.0000000862&0.0000003446&-0.0000001436\\-0.0000001436&-0.0000001436&-0.0000001436&-0.0000001436&0.0000003590\end{bmatrix}$$

The standard deviation of the bays was computed as, σ=±0.0005870264*m*.

The study demonstrated the use of Total Station and the application of least squares by method of observation equation in the establishment of an Electromagnetic Distance Calibration Base at the Federal University of Technology, Minna. The analysis of the obtained 200 sample data set yielded the most probable value for the four bays as; and an instrument constant K= -0.0047m.

The standard error of the unknown parameter was determined as:σ = ±0.0005870264m.

The hypothesis test carried out on the obtain result indicate that the adjustment process was consistent and without distortion. and an instrument constant K= -0. 0047m.The analysis of the obtained 200 sample data set yielded the most probable value for the four bay; $X_1$ =101.650m, $X_2$ =199.7968m, $X_3$ = 299.9189m, $X_4$ =502.6423m.

Hypothesis testing of the obtain result was done to check if the so obtained result and the procedures used can be relied upon. A test statistic is computed from the sample values (the observations) and from the specifications of the null hypothesis. If the test statistic falls within a critical region, the null hypothesis is rejected. That is, $V^T$PV is statistically tested to see whether it falls within the specified confidence limit or not. This is done by means of a two tailed test of variance chi square $x^2$ test. The formation of the hypothesis is as follows;

$H_0; \sigma_0^2 = V^TPV, H_1; \sigma_0^2 \neq V^TPV.$

The zero hypothesis states that the prior variance of the unit weight statistically equals the a-posterior variance of unit weight. If the zero hypothesis is accepted, the adjustment is judged to be correct. But if the numerical value is such that; $x^2 \propto x^2_{n-1,1-\alpha/2}$, $x^2 \propto x^2_{n-r,\alpha/2}$the zero hypothesis is rejected. This is a two tailed test where the Alternative Hypothesis ( $H_1$ ) is rejected if the computed statistics is outside the confidence limit. The confidence limits are the upper limit and the lower limit of the statistics table. They are obtained in the statistics table as, $x^2 \propto x^2_{n-1,1-\alpha/2}$ for upper limit and $x^2_{n-r,\alpha/2}$, for lower limit, where α is the level of significance.

The result of the hypothesis testing reveals that $V^T$PV = 0.0028 T, at 0.05 level of significance (α), with a degree of freedom of 195. The computed value for the chi square is given as;

$x^2 = \left(\frac{V^TPV}{\sigma_0^2}\right)$lower limit and upper limit as obtained from the statistical table is given as 0.052 and 6.23 respectively.

## CONCLUSION

The study demonstrated the use of Total Station and the application of least squares by method of observation equation in the establishment of an Electromagnetic Distance Calibration Base at the Federal University of Technology, Minna. The EDM Calibration Baseline which was established on a straight-line configuration was divided into four bays. The analysis of the obtained 200 sample data set yielded the most probable value for the four bays as; and an instrument constant K= -0.0047m and a standard error:σ = ±0.00058m. The study recommended for the establishment of indoor calibration baseline that would be free from the effect of the atmospheric conditions on measured distance in further studies.

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