

Manual

Electronic Distance Measurement Calibration Baseline

National Land Commission Secretariat





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Introduction

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. There are three types of errors that can be verified on the reference baseline. They are scale error, constant/zero error, and cyclic error, which affect EDM's scale and additive constant.

Moreover, due to the rapid evolution of more precise instruments with various branding with varying unit lengths, the instrument might have different measurements based on the manufacturer's specification. On what basis should those measurements made by the instrument be certified? To bring the spatial data to common standardized measurement, the instrument should be calibrated and verified on the certified known baseline.

The Heerbrugg/Schwendener baseline adopted at Yangthag, Haa features an almost equal distribution of the distance measured in all combinations over the baseline length and as well as over the unit length of the distance measured. The design has seven concrete stations, provides 21 observations in all combinations, and has a total length of 849m. This design permits the detection of all distance-dependent errors and also short periodic error.

The certified baseline must be capable of being calibrated with an uncertainty of $\pm (1.5 + 20 \cdot 10^{-3} L)$ mm at the 95% confidence level, where L is the interval length in meters. It is recommended that, in general, the minimum standard for the uncertainty of calibration of an EDM is $(4.00 + 20 \cdot 10^{-3} L)$ mm at the 95% confidence level.

This guideline briefly presents the calibration strategy and practical solution for surveyors who intend to or by law/regulation need to verify the Electro-optical distance meter (EDM) based on a reference baseline. It illustrates the procedure to be followed for proper EDM calibration to achieve better accuracy and precision. The mathematical formulae used in the excel spreadsheet for Additive Constant and Scale Factor which is Prepared by Bruce Harvey, Surveying and SIS, UNSW have been illustrated in this document. It shows how the measured slope distances for inter-pillars are corrected for first velocity correction and geometric correction.

Theory of EDM

It is important to understand the terms Verification and calibration in this context. The verification of the EDM baseline is carried out periodically with the precise EDM instrumentation. The instrument used by the National Land Commission to verify the baseline is Trimble S9 1" DR HP. This process determines the true inter-pillar distances and establishes traceability because the baseline becomes a subsidiary standard of the international meter. EDM calibration on the verified baseline is done to determine the instrument correction to be applied on EDM to achieve true inter-pillar distances, thereby establishing the traceability of its measurements to the national standard.

Calibration is done for a number of reasons, the most important ones are:-

- **Quality control.**

Before purchasing, the instrument has to be checked for quality to ensure that it meets the manufacturer's specification. If properly calibrated, sometimes the instrument will perform much better than the manufacturer's specification.

The instruments are scheduled to calibrate half-yearly or year because the instrument constant will not always be reliable and not durable with time.

- **Improvement of accuracy.**

If EDM features addition and repeatable systematic errors, then it can be calibrated and verified on the baseline and compensated for the errors by application of correction, thereby increasing the accuracy of the instrument.

- **Legal metrology (Required by State or international law).**

Any surveyors doing survey work should have a legal obligation to ensure that their instrument is standardized and capable of achieving the accuracy stated by survey standards.

Instrument Errors

Additive constant (correction for zero-index error)

All distances measured by a particular EDM/reflector combination are subject to a constant error. It is caused by three factors:

- Electrical delays, geometric detours, and eccentricities in the EDM,
- Differences between the electronic center and the mechanical center of the EDM,
- Differences between the optical and mechanical centres of the reflector.
- The additive constant or zero/index correction is added to measured distances to correct for these differences.

Scale error

The scale error is linearly proportional to the length of the line measured. These can arise from:

- variations in the modulation frequency of the EDM,
- non-homogeneous emission/reception patterns from the emitting and receiving diodes (phase inhomogeneities),
- variations in atmospheric conditions which affect the velocity of propagation,
- errors in the collection and use of atmospheric data. This includes the use of uncalibrated thermometers/barometers, not taking atmospheric measurements in the shade, and the incorrect entry of the atmospheric correction into the EDM.

Cyclic error

Cyclic is caused by the non-linearity in the amplitude of the carrier wave and phase measurement. It is usually sinusoidal in nature with a wavelength equal to the unit length of the EDM. The unit length is the scale on which the EDM instrument measure the distances, and is derived from the fine measuring frequency. Unit length is equal to the one half of the modulation wavelength of an EDM (Rüeger, 1996).

As the cyclic error repeats itself for every unit length contained within a measured distance, its sign and magnitude vary depending on the length measured. Cyclic error is known to increase in magnitude as the

instrument's components age (Janssen, 2015).

General Procedure for EDM calibration

The following procedure is based on Rueger (1974) and is to be followed strictly while calibrating.

1. Booking Sheets.

All the measurements taken should be recorded in the booking sheet officially published by National Land Commission (Annexure 1). When mistakes occur, each mistake shall be crossed out, not erased or made illegible, and the correct value entered alongside. All such alterations shall be signed or initialed by the person correcting, and the date of change should also be recorded.

All details (Model, Serial No, and Make) of the instrument and reflector should be recorded as per the manufacturer's specification. The instrument parameters for velocity correction (constant C and D) should be recorded as per the instrument parameter manual. The sheet should be signed and dated by the observer.

The unit for measurements is metered (distance), degree Celsius (temperature), and millibars (pressure).

2. Set up and shades.

The instrument must be shaded by an umbrella at all times during the calibration because the scale of EDM is temperature-dependent and must be referenced against ambient air temperature. The instrument shouldn't be put in the box or left under direct sunlight. The instrument must be switched on and allowed to warm up for 15mins under the shades before commencing. To improve the calibration accuracy, an umbrella may also be used to shade the reflector.



3. Atmospheric Correction control.

Determine whether or not the EDM is a pulse distance meter.

If not, then the atmospheric correction control (ppm) should be set to zero if possible. For instruments requiring meteorological observations to be input, enter the temperature and pressure for which the instrument is standardized (i.e.: ppm = 0).

If the EDM is a pulse distance meter, then the ambient temperature and pressure must be entered into the EDM before observing each inter-pillar distance.

4. Metrological Observations.

The field equipment (thermometer, Hygrometer, Barometer) should also be calibrated against the standard equipment.

Temperature ($^{\circ}\text{C}$) must be measured in the shade at both the instrument and reflector. Temperature is measured at instrument/reflector height and is to be observed for each inter-pillar interval. For each line, the line mean temperature is computed.



The atmospheric pressure (Mb) must be measured in the shade at the instrument station for each inter-pillar distance. To obtain a higher accuracy calibration, atmospheric pressure can also be observed in the shade at the reflector, for each inter-pillar interval.

The significance of errors in the meteorological observations on the EDM distance can be summarized as follows:

- An error in temperature of 1°C affects the distance by 1ppm
- An error in pressure of 1hPa affects the distance by 0.3ppm

Although humidity has only a small effect on EDM measurements, relative humidity (%), or wet bulb

temperature observations can be taken to further improve the accuracy of the calibration.

5. Power.

The power of the instrument must be switched on at all times during the calibration. On each line, four different measurements should be taken as a minimum (Manually record the slope distance on the booking sheet).

6. Height of instrument.

The height of the instrument should be measured above the mounting plate to the axis of the instrument and accurately noted on the booking sheets. The height must be measured with pocket tape in four cardinal directions and record the mean height. The same reflector, reflector mounting, and tribrach should be used. If it is not possible to measure the longer distances with one reflector use a multiple reflector mounting/tribrach. The height of the reflector should be measured the same as EDM and accordingly note on the booking sheets.

The height above the pillar should be measured to an accuracy of one millimeter. These heights are combined with the height of the pillar plate to reduce the distance to the horizontal.

7. Leveling of Instrument.

Check the leveling bubbles for all the tribrach, reflector, and the EDM, and if necessary, adjust before commencing. The field form featuring leveling must be ticked after leveling of EDM/Reflector.

8. Condition.

The calibration must be done fully during the daytime or fully during the nighttime. The mixture of day and night is not acceptable. If instruments were used during the daytime, they should be calibrated during the daytime, and if the instruments are typically used in underground mines/tunnels then they should be calibrated at night. The reason for doing this process is that the additive constant may differ between daytime and nighttime operation.

9. Sequence of measurement.

The observation sequences should be chosen in such a way that shorter lines are measured first and longer lines later. By the time long-distance are measured, the frequency has stabilized because of leveling up of acclimatization and warm-up processes.

Set up the instrument on pillar 1 and measure pillars 2, 3, .and 7.

Then move the EDM to pillar 2 and measures pillar 3, 4.....and 7

Eg: - 1----- 2,3,4,5,6,7

2----- 3,4,5,6,7

3----- 4,5,6,7

4----- 5,6,7

5----- 6,7

6----- 7

A total of 21 observations should be recorded.

10. Comparison of Reflectors

Once all inter-pillar distances have been measured to the one uniquely identified reflector, compare this reflector with the remaining reflectors by measuring each in turn. This should be performed on the shortest line by comparing the slope distances. However, if reflectors vary in height, horizontal distances should be observed.

Where found to be significant, variations should be applied as corrections to the additive constant. It is for this reason that all reflectors should be uniquely numbered.

Subsequent calibrations of the EDM should be performed using the same uniquely numbered reflector to compile a calibration history for the instrument/reflector combination.

Calibration Frequency

The instruments should be calibrated at least every 12 months to the national standard measurement. And also calibrated at the time of purchasing instruments (to check the manufacturer's specification) and after the repairs.

Calibration Accuracy

The minimum standard for the uncertainty of calibrations of an EDM instrument used for cadastral surveys should be $\pm (4.0\text{mm} + 20\text{ppm})$ at the 95% confidence level. And in terms of standard deviation, the instrument correction must be accurate to at least $\pm (2.0\text{mm} + 12\text{ppm})$.

Note that the uncertainty and standard deviations listed above refer to the accuracy of the instrument correction and not to the precision of distance

measurement. The expression does not relate in any way to the accuracy specification quoted by manufacturers for their instruments

Initial Processing

The First Velocity Correction.

First velocity correction (ppm correction) is applied because the ppm knob was set to zero in the instrument at the time of verification. The formula is given below:-

$$d_1 = d_{mea} + K_a$$

$$K_a = \left[C - \frac{D * p}{273.15 + t} + \frac{11.27e}{273.15 + t} \right] 10^{-6} d_{mea}$$

K_a = First velocity correction
 C = modulation frequency
 D = carrier wavelength
 P = pressure in millibars

Computation of partial water vapor pressure from relative humidity

$$e = E'_w \cdot h / 100$$

e = Partial water vapour pressure in hectapascals
 E'_w = saturation water vapour pressure (hpa) at the dry bulb temperature.
 h = Relative humidity in percent.

$$E'_w = [1.0007 + (3.46p)10^{-6}] \times 6.1121 \exp \left[\frac{17.502t}{(240.94 + t)} \right]$$

Correction of Slope distance (D) for height variation on the baseline

The corrected mean slope distance is reduced to the horizontal distance at the mean elevation of two pillars using the following formula.

$$d_{hor} = d_1 - S_{cor}$$

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3} + \frac{\Delta h^6}{16d_1^5}$$

If the gradient between two pillars is less than 4 %, then the third term may be ignored.

dhor = Horizontal distance
 d1 = corrected slope distance
 Scor= Slope correction
 Δh = height difference between instrument and reflector
 Δh = height of instrument axis above pillar(HI) + height of Pillar (HA) – Height of reflector above pillar (HT)- height of target pillar(HB)

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3}$$

Height Correction.

The reduced horizontal distances should be reduced to the height of the lowest pillar. The Height correction is significant when the baseline is steeper. If this correction is not applied on the reduced horizontal distance then the error of 1ppm of 6.73m height difference of mean elevation between two pillars and the height of the lowest pillar.

$$d = d_{hor} \cdot \frac{R + h_0}{R + h_m}$$

d= reduced horizontal distance.
 R= radius of earth (6370100)
 h₀= height of lower pillar
 h_m=height of mean elevation
 d_{hor} = horizontal distance at mean elevation

Least square adjustment of Additive constant and Scale factor

The least-square solution is given by the following formula.

$$X = (A^T P A)^{-1} A^T P W$$

X= Least squares estimated instrument index, scale and cyclic correction.

AT= Transpose Matrix of coefficient.

A= Matrix of coefficient.

P= Weight Matrix.

W= Misclose vector.

Observation Equation.

The observation equation for each measured distance can be derived as follow:

$$V_{ij} = \Delta X_j - \Delta X_i - a_0 - [D_{ij} - (X_j^0 - X_i^0)]$$

X_i^0 = Original Baseline distance X_i

X_j^0 = Original Baseline distance X_j

ΔX_i = Correction to X_i^0

ΔX_j = Correction to X_j^0

D_{ij} = Measured distance by the prescribed EDM instrument between pillar i and j

V_{ij} = Residual of the distance between pillar i and j

a_0 = Additive constant of the prescribed EDM instrument.

For example:-

$V_{12} =$	$-\Delta X_2$			$-a_0$	$-[D_{12} - (X^0_2 - X^0_1)]$
$V_{13} =$		$-\Delta X_3$		$-a_0$	$-[D_{13} - (X^0_3 - X^0_1)]$
$V_{14} =$			$-\Delta X_4$	$-a_0$	$-[D_{14} - (X^0_4 - X^0_1)]$
$V_{23} =$	ΔX_2	$-\Delta X_3$		$-a_0$	$-[D_{23} - (X^0_3 - X^0_2)]$
$V_{24} =$	ΔX_2		$-\Delta X_4$	$-a_0$	$-[D_{24} - (X^0_4 - X^0_2)]$

Where $A = \begin{bmatrix} -1 & 0 & 0 & -1 & 0 & -1 & 0 & -1 & 1 & 1 & 0 & -1 & -1 & 0 & 1 & -1 & -1 \\ V_{12} & V_{13} & V_{14} & V_{23} & V_{24} & V_{34} \end{bmatrix}$ $X = [\Delta X_2 \ \Delta X_3 \ \Delta X_4 \ a_0]$ $W = [-[D_{12} - (X^0_2 - X^0_1)] \ -[D_{13} - (X^0_3 - X^0_1)] \ -[D_{14} - (X^0_4 - X^0_1)] \ -[D_{23} - (X^0_3 - X^0_2)] \ -[D_{24} - (X^0_4 - X^0_2)] \ -[D_{34} - (X^0_4 - X^0_3)]]$

A weight matrix can be determined for the observed distances according to their accuracy

$$P = \sigma^2_0 C^{-1} = \begin{bmatrix} P_1 & 0 & \dots & 0 & 0 & P_2 & \dots & 0 & \dots & \dots & \dots & 0 & 0 & \dots & P_n \end{bmatrix}$$

Usually, $\sigma^2_0 = 1$, which means that the input variance is not scaled and the weight of the jth distance is

$$P_j = 1/S^2_0$$

Where S_0 is the standard deviation of the measured jth distance.

The observation equation for all distance measured on a baseline can be expressed in a matrix form as

$$V = AX + W$$

Analysis of the least-squares results

The cofactor matrix of the parameters is:

$$Q_{xx} = S^2 (A^T P A)^{-1}$$

Estimated variance factor $S^2 = \text{Minimum} / (\text{Degree of freedom})$

Where $\text{Minimum} =$

$$\text{Minimum} = \sum \left(\frac{V}{S} \right)^2$$

v= residual between fixed distance and
adjusted distance
s= Standard deviation of the measured line
d= degree of freedom= n-u
n= number of observed lines
u= number of parameters (a₀, a₁, b₁...)

The standard deviation of the instrument index, scale correction, and cyclic errors can be derived by taking the square root of the diagonal elements from the equation $(A^T P A)^{-1}$

A 95% confidence level is obtained by multiplying the standard deviation by $t_{95\%, d}$ where t stands for the student's t-distribution.

Reference

- Rüeger, J. M, Electronic Distance Measurement. Third Totally Revised Edition
- Rüeger, J. M, Instructions on the Verification of Electronic Distance Meters according to section 10, Weights and Measures (National Standards) Act, 1960, School of Surveying, University of New South Wales. P.O. Box 1, Kensington, N.S.W. 2033
- Rüeger, J.M. (1991) 'Legal Calibration of Electronic Distance Meters in Australia', The Australian Surveyor, Vol 36, Sept 1991, pp195-212.
- Land Gate. Government of Western Australia. "Calibration of Electronic Distance Measurement Instrument". Last updated 2017.
- N.W.J. Hazelton. "Instrument Calibration for the 21st Century"
- Fronczek, C. J., 1977: Use of calibration base lines. NOAA Technical Memorandum NOS NGS10, 38 pp. National Geodetic Information Center, Rockville, MD 20852. Currently available at: http://www.ngs.noaa.gov/PUBS_LIB/TMNOSNGS10.pdf

Annexure 1. Booking Sheet

Calibration Booking Sheet.

Job Name: _____ Observation Date: _____ Time: _____
am/pm

Observer Name: _____ . CID Number :

Instrument Make: LEICA .

Instrument Model: TS06 . Serial No. : 1234567

Instrument owner: NLCS .

Prism Make: LEICA .

Prism Model: GRZ Serial No. : 12345

Prism Owner: NLCS

Unit Length of Instrument: 1.5m

Constant C:

Constant D:

Checklist

- Battery OK.
- Instrument shaded.
- Instrument set to read slope distance.
- Atmospheric correction set to zero ppm.
- Height measure above base of tribach.

Signature of Observer

EDM CALIBRATION

Thermometer		
	Make	Serial No.
I		
R		
Barometer		
	Make	Serial No.
I		
R		



EDM CALIBRATION CERTIFICATE

Minimum standard for the uncertainty of calibration of an EDM instrument is 4.00 mm + 20.00 ppm and all uncertainties are specified at the 95 % confidence level.

DISTANCE (Meters)	INSTRUMENT UNCERTAINTY (mm)	MINIMUM STANDARD (mm)	COMPARISON TEST	
			PASS	FAIL
50		5.00		
100		6.00		
300		10.00		
400		14.00		
600		20.00		
800		26.00		

Uncertainty of instrument correction: ± (..... mm + ppm)

This instrument:

- Satisfy the National Land Commission's minimum standards.
 Doesn't satisfy the National Land Commission's minimum standards.

FIRST VELOCITY CORRECTION (ATMOSPHERIC CORRECTION)

$$\text{Correction} = \left[C - \frac{D \cdot p}{273.15 + t} + \frac{11.27e}{273.15 + t} \right] 10^{-6} d_{\text{meas}}$$

Where t = Dry Temp (Celsius), P = Barometric pressure (hectapascals)
 e = partial Vapour Pressure (hectapascals)

The first velocity correction is based on a velocity of light of 299792458.00 m/s and on the refractive index formulae recommended by the International Association of Geodesy in 1993.

Calibrated by :

Approved by :

Name/ CID :

Name :

Designation :

Designation :

Date :

Date :