DETERMINATION OF ZERO ERROR OF ELECTRO-OPTICAL DISTANCE MEASURING INSTRUMENTS

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ABSTRACT

EODM instruments are classified into two groups, viz. microwave and electro-optical distance measuring instruments. Each pair of microwave instruments or an electro-optical instrument coupled with its reflector has some error when the distance measured with it is compared with the accurately known distance. This paper describes two methods of determining such error. One method requires an accurate base line established by using Invar wires while the other method does not require an accurate base line but simply a line having some sections. Based on experimental results, it is concluded that in order to determine zero error accurately, one should either use an Invar base or sufficient measurements should be taken of different sections of an unknown line.

INTRODUCTION

One of the important aspects of surveying is to acquire data on distances between the terrestrial points to be plotted on maps. Earlier, this work was done using only mechanical devices (viz. wires, tapes, bands, etc.), which involve a lot of labour and time. Since the introduction of electro-optical instruments in surveying, it has become possible to make linear distance measurements with greater accuracy. Uncertainties in measurement are still encountered owing to meteorological variations and instrument changes[1]. In the electro-optical distance measuring (EODM) instruments, the use of infrared light as carrier for the high-frequency measuring (modulating) wave, has reduced these uncertainties to a great extent. But to achieve accuracy of high order in precision geodetic first-order surveys and other engineering project surveys, these uncertainties must be carefully considered.

Refractive index, determined by the meteorological conditions prevailing at the time of measurements is applied as a correction factor to the measured distance. An incorrect determination produces error in distance. An error of one part per million (1 ppm) in the distance is caused by 1°C error in temperature, 2.5 mm error in air pressure and 19 mm error in water vapour pressure[2]. Other meteorological factors which affect the intensity and hence the propagation of infrared light are rain, snow, fog, haze and simmering due to excessive sun radiation. These lead to reduction of measuring range and accuracy.

Instrument changes are essentially a function of three parameters, viz. periodic error, operational error and instrument constant. Periodic error arises owing to modulation frequencies and the mutual effect of transmitter, receiver and phase measuring device, and can be minimized by suitable adjustments in the laboratory. An operational error is a result of eccentricity, malalignment, insufficient levelling, incorrect elevation between instrument and reflector, etc., and can be almost eliminated by an expert observer. Instrument constant (zero error) takes into account the difference between the measured value and the actual known distance. Investigations relating to the methods of zero error measurement and the results obtained are presented and discussed here.

INSTRUMENT CONSTANT (ZERO ERROR)

Instrument constant in the case of electro-optical infrared distance measuring instruments applies to a given instrument and its reflector in combination. Every manufacturer determines and indicates the instrument constant before supplying each instrument. Some manufacturers adjust instrument constant to zero and do not furnish any instrument constant information with the instrument. It is desirable to redetermine the value of instrument constant after every transhipment, major repairs, etc.

Instrument constant can be determined by measuring lines of known and unknown lengths. There are some established base lines of known lengths in different parts of India.

MEASUREMENT OF A KNOWN BASE LINE

Measurements on a single section

Ten measurements were made on one of the sections of a base line established by Invar wires with an electro-optical short-range instrument. The values are shown in table 1 and plotted in figure 1. The measurements were made at noon hours in cloudy weather during a drizzle. The prevailing temperature was 29°C and the atmospheric pressure was 692 mm of mercury. Atmospheric index correction of 69 ppm was fed to the instrument and, as a result, every measurement was corrected automatically for the refractive index.

To these measurements, the pre-determined (by the manufacturer) value of total off-set correction (zero error), +212 mm, was also applied. In spite of this, deviation was +13.7 mm [known value, 179.9654 m, minus mean measured value, 179.9517 m, = +13.7 mm, the difference]. This shows the need for re-determination of instrument constant. In other words, had the off-set correction of +212 mm not been applied, the zero error, so determined, would have come to 212+13.7=225.7 mm (or +226 mm).

Table 1 *One set of observations on a single section of a base line*

1.	179.952 m
2.	179.954
3.	179.952
4.	179.950
5.	179.951
6.	179.951
7.	179.951
8.	179.952
9.	179.953
10.	179.951
Mean =	179.9517 m

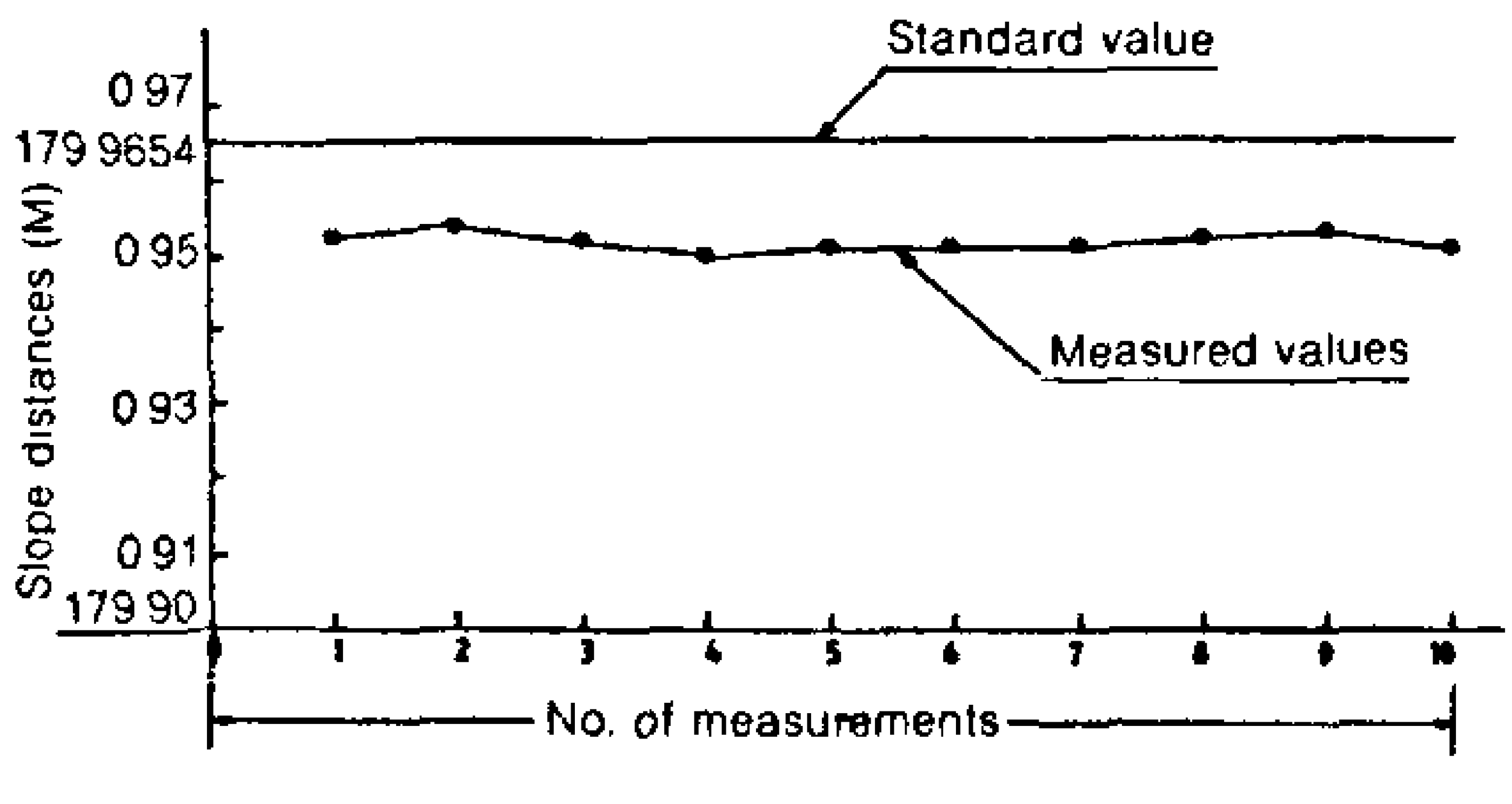

Figure 1. Observations on a section of known base line.

A single set of observations cannot be regarded as sufficient for determining instrument constant. Two more sets, each containing ten measurements, were obtained with the same instrument, one in summer and another in winter. The mean values, thus obtained, are shown in table 2. The difference between the known value and the mean of the three means obtained at different times was +10.6 mm. Again it included the total off-set correction of +212 mm supplied by the manufacturer. This means that the new instrument constant is +223 mm. Obviously it is less than that determined with a single set of observations as above. This shows that the zero error, determined with more sets of observations, is more accurate than that obtained with a single set of observations on a known section of a base line.

Measurements on more than one section of a base line

Some of the segments of a 1 km base line established by Invar wires were measured with the same instrument and the means (of ten measurements) for the segment are given in table 3. The instrument constant based on the mean measurements for five sections is +205 mm. While making these measurements the manufacturer's total off-set correction (TOC) of +212 mm (proposed to be applied) has not been applied. It is observed that the difference between the determined instrument constant and the manufacturer's TOC is +7 mm, which is much less than that based on measurements on only one section of a base line. This and other values of zero error are given in table 4. Thus it appears that, for determining zero error, measurement of more

Table 2 *More than one set of observations on a single section of a base line*

Mean measured value (m)	Net mean value (m)	Known value (m)	Difference (mm)
179.9517 179.9300 179.9826	179.9548	179.9654	+10.6

Table 3 *A single set of observations on more than one section of a base line*

Known value (m)	Measured value (m)	Difference (mm)	Mean value of the diffe-rence (mm)
479 822	479 611	+211	
99.982	99.784	+198	
79.983	79.780	+203	+205
119 939	119 739	+200	
179 918	179.707	+211	

sections of a base line leads to better results than measurement of a single section of base line.

MEASUREMENT OF AN UNKNOWN BASE LINE

In the absence of standard base lines, there is a conventional method to measure an unknown distance D directly and then partly, such as d_1 and d_2 as shown in figure 2 (ii). The determination of additive constant (zero error) is based on the following formula:

$$\text{Additive constant} = D-(d_1+d_2). \quad (1)$$

In general,

$$\text{Additive constant}^3 = \frac{D-\sum_{i=1}^{n} d_i}{n-1}, \quad (2)$$

where D is the total distance (AC in figure 2) containing n sections (like d_1, d_2, $d_3 \ldots d_n$ as in figure 2 (i)). If the number of sections is only 2, (i.e. $n=2$), formula (2) reduces to formula (1).

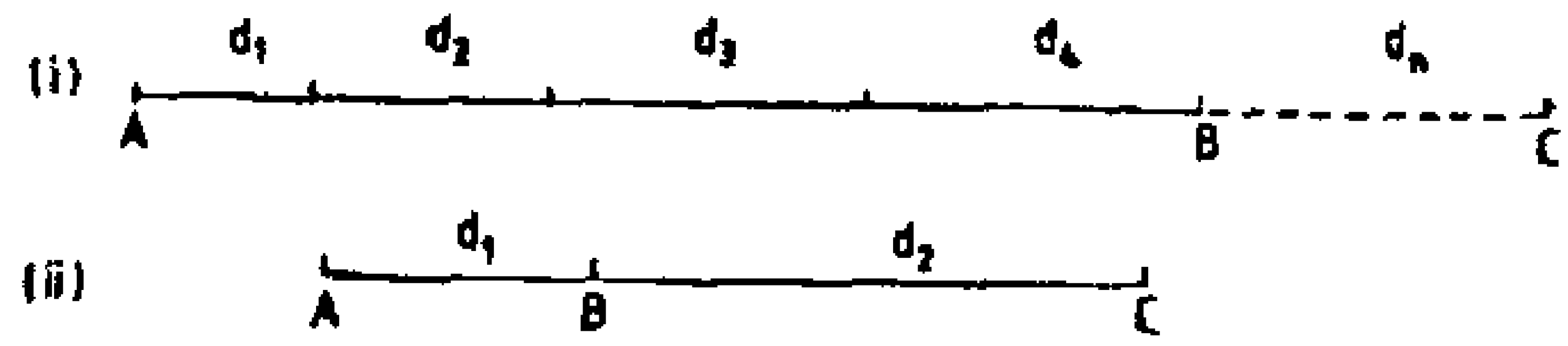

Figure 2. An unknown base line.

Using two sections of the line

If sufficient measurements are not made, this method is not considered accurate, but it is still sufficient for the purpose of obtaining additive constant to serve as a field check. This has been practically proved while measuring with a short-range electro-optical distance meter. Two segments AB and BC of the line were measured along with the entire length AC. Table 5 also shows, in column 3, zero error determined from the measured values. As the known values of the sections were also available, it was possible to determine zero error by the known base line method also, as shown in column 6 of the table 5. As the zero error claimed by the manufacturer was 0, the value obtained by the known base line method (column 6 of table 5) was nearer to it than that determined by the unknown base line method (column 3 of table 5).

Using more than two sections of the line

To determine additive constant more precisely by the unknown base line method, seven points may be

Table 4 *Refinement of zero error of a given instrument*

ZE supplied by manufacturer	+212 mm
ZE determined from single set of observations on a single section of a base line	+226 mm
ZE determined from more sets of observations on a single section of a base line	+223 mm
ZE determined from single set of observations on more than one section of a base line	+205 mm

Table 5 *Comparison between unknown base line and known base line methods of a zero error determination*

Base line section	Measured value (m)	ZE by formula 1, AC−(AB+BC) (mm)	Known value (m)	Difference (ZE) (by known base method)	Mean ZE (mm)
AC	999.743		999.746	+3 mm	
AB	299.898	−2	299 899	+1 mm	+1.3
BC	699 847		699.847	0 mm	

taken instead of three. A very long line should always be avoided to eliminate any atmospheric or stray-light effects. The points, and hence the distances of the six sections, may be selected so that all the intermediate distances are different and uniformly distributed between the longest and the shortest distances, as is apparent from figure 3. In this way twenty-one independent distance measurements are possible (table 6).

Six sections of a line can give fifteen values of zero

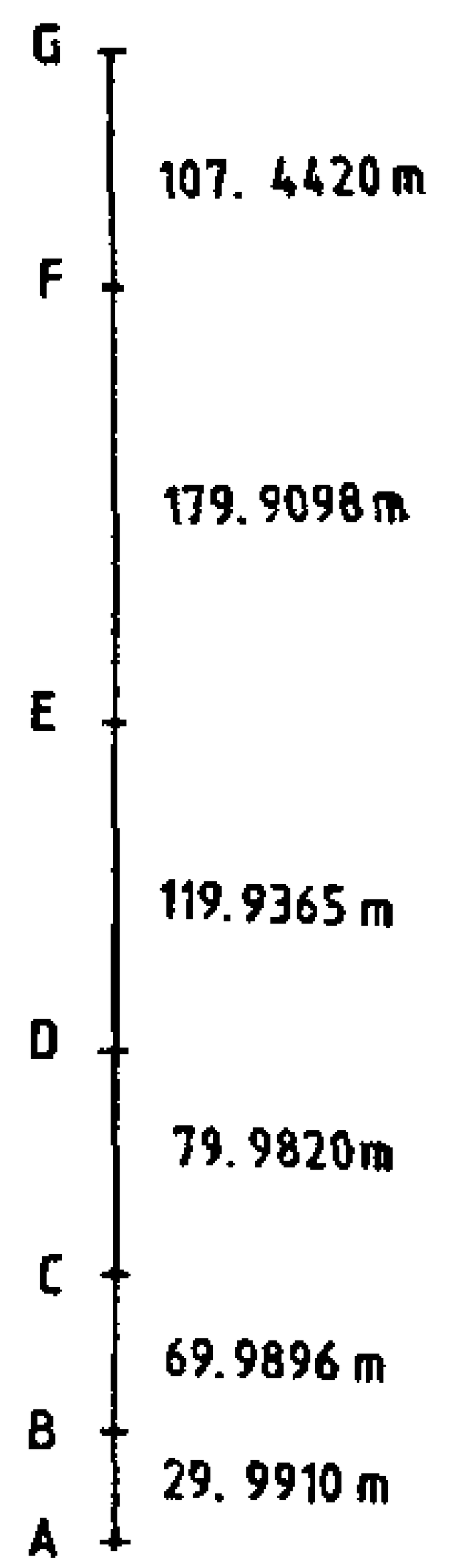

Figure 3. Six segments of a known base line.

Table 6 *Twenty-one independent distances from six sections of a line AG*

AB, AC, AD, AE, AF, AG
BC, BD, BE, BF, BG
CD, CE, CF, CG
DE, DF, DG
EF, EG
FG

error by formula (2). The mean of these will give the accurate value.

The additive constant of an electro-optical infrared distancer has been calculated below, based on 21 measurements (table 7). The mean value is −4.3 mm.

1. $\dfrac{D_{AG}-(d_{AB}+d_{BC}+d_{CD}+d_{DE}+d_{EF}+d_{FG})}{6-1}=-0.0042\,\text{m}$

2. $\dfrac{D_{AF}-(d_{AB}+d_{BC}+d_{CD}+d_{DE}+d_{EF})}{5-1}=-0.0023\,\text{m}$

3. $\dfrac{D_{AE}-(d_{AB}+d_{BC}+d_{CD}+d_{DE})}{4-1}=+0.0018\,\text{m}$

4. $\dfrac{D_{AD}-(d_{AB}+d_{BC}+d_{CD})}{3-1}=+0.0013\,\text{m}$

5. $\dfrac{D_{AC}-(d_{AB}+d_{BC})}{2-1}=+0.0013\,\text{m}$

6. $\dfrac{D_{BG}-(d_{BC}+d_{CD}+d_{DE}+d_{EF}+d_{FG})}{5-1}=-0.0048\,\text{m}$

7. $\dfrac{D_{BF}-(d_{BC}+d_{CD}+d_{DE}+d_{EF})}{4-1}=-0.0029\,\text{m}$

8. $\dfrac{D_{BE}-(d_{BC}+d_{CD}+d_{DE})}{3-1}=-0.0025\,\text{m}$

9. $\dfrac{D_{BD}-(d_{BC}+d_{CD})}{2-1}=+0.0021\,\text{m}$

10. $\dfrac{D_{CG}-(d_{CD}+d_{DE}+d_{EF}+d_{FG})}{4-1}=-0.0082\,\text{m}$

11. $\dfrac{D_{CF}-(d_{CD}+d_{DE}+d_{EF})}{3-1}=-0.0080\,\text{m}$

Table 7 *Twenty-one mean values obtained between seven points of an unknown line (each value is a mean of ten measurements; values are in metres)*

Points	B	C	D	E	F	G
A	29.9814	99.9711	179.9559	299.9042	479.8110	587.2501
B	—	69.9884	149.9740	269.9126	449.8299	557.2705
C	—	—	79.9835	199.9218	379.8344	487.2769
D	—	—	—	119.9456	299.8532	407.3004
E	—	—	—	—	179.9212	287.3636
F	—	—	—	—	—	107.4511

12. $\dfrac{D_{CE}-(d_{CD}+d_{DF})}{2-1}$ $= -0.0073$ m

13. $\dfrac{D_{DG}-(d_{DE}+d_{EF}+d_{FG})}{3-1}$ $= -0.0088$ m

14. $\dfrac{D_{DF}-(d_{DE}+d_{EF})}{2-1}$ $= -0.0136$ m

15. $\dfrac{D_{EG}-(d_{EF}+d_{FG})}{2-1}$ $= -0.0087$ m

Mean additive constant $= -0.0043$ m

$= -4.3$ mm.

COMPARISON OF KNOWN BASE LINE AND UNKNOWN BASE LINE METHODS

The additive constant of the same instrument was determined from twenty-one measurements on a known base line with six sections (table 8). The mean value is −4.1 mm. This is quite close to the value of −4.3 mm derived by the unknown base line method. This shows that if sufficient measurements (twenty-one or more) are taken, zero error (additive constant or instrument constant) determined by the two methods will be almost identical.

Table 8 *Additive constant by known base method*

Segment	Standard value, a(m)	Measured value, b(m)	Difference (zero error), (a–b)m
AB	29.9910	29.9814	+0.0096
AC	99.9806	99.9711	+0.0095
AD	179.9626	179.9559	+0.0067
AE	299.8991	299.9042	−0.0051
AF	479.8089	479.8110	−0.0021
AG	587.2509	587.2501	+0.0008
BC	69.9896	69.9884	+0.0012
BD	149.9716	149.9740	−0.0024
BE	269.9081	269.9126	−0.0045
BF	449.8179	449.8299	−0.0120
BG	557.2599	557.2705	−0.0106
CD	79.9820	79.9835	−0.0015
CE	199.9185	199.9218	−0 0033
CF	379.8283	379.8344	−0.0061
CG	487.2703	487.2769	−0.0066
DE	119.9365	119.9456	−0.0091
DF	299.8463	299.8532	−0.0069
DG	407.2883	407.3004	−0.0121
EF	179.9098	179.9212	−0.0114
EG	287.3518	287.3636	−0.0118
FG	107.4420	107.4511	−0.0091
		Total	−0.0868

Mean additive constant = −4.1 mm.

CONCLUSIONS

It is desirable to redetermine the value of zero error (instrument constant) after every transhipment or repairs carried out from time to time.

Instrument constant determined by several observations (ten or more) on a *single section* of a base line cannot be recommended; that determined using a *number of sections* will lead to a reasonably accurate value.

In the absence of a known base line, an approximate additive constant can be determined by measuring two segments of an unknown line and its full length. But to achieve an accurate value it is necessary to make more observations, such as twenty-one measurements on six segments of an unknown line. The result so obtained will be as accurate as that obtained with twenty-one observations on six sections of a known base line.

The methods detailed above are applicable for other types of EODM instruments also.

PRECAUTIONS

While making base lines the following precautions should be taken:

1. The line should not be more than 500 m long, so that uniform atmospheric conditions can be obtained throughout the length during distance measurements.

2. All the points (stations) should be adequately aligned to be on the same line.

3. The lengths of sections should be chosen in such a way that the finer parts of the various distances (say twenty-one) fall uniformly on measuring wavelength.

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1. Burnside, C. D., *Electronic distance measurement*, Crosby Lockwood Staples, London, 1977, Chapters 2 & 8, p. 1.
2. Bevin, A. J. and Forster, T. A., *Evaluation of the laser geodimeter for precise measurement*, 1973.
3. Schwendener, H. R., *Electronic distances for short ranges: Accuracy and checking procedures*, Survey Review, 1972, April–June, p. 273.

ANNOUNCEMENTS

WEATHER INFORMATION CARDS

Shri D. Krishna Rao, Retired Director, Indian Meteorological Service, Mysore, has published three weather guides. The guides, printed on plastic-coated cards, are 1. Karnataka Weather (Rs. 2), 2. Mysore City Weather (Rs. 2), and 3. Bangalore Weather (Rs. 4).

The cards can be had from Shri D. Krishna Rao, 'Margosa Lodge', Ch. 1 Krishnaraja Boulevard, Chamarajapuram, Mysore 570 004.

ANNUAL SESSION OF THE ACADEMY OF ENVIRONMENTAL BIOLOGY, INDIA

The tenth annual session of the Academy of Environmental Biology, India, will be held at Madras from 13 to 17 December 1989. On the occasion an international symposium on Environmental Impact on Biosystem is planned. *Deadlines*: for abstracts, 31 July 1989; for full-length papers, 31st August 1989, with registration fee (Rs. 250). For details write to the Academy at 657/5 Civil Lines (South), Muzaffarnagar 251 001, or to Dr M. Selvanayagam, Organizing Secretary, Department of Zoology, Loyola College (Autonomous), Madras 600 034.