Optimization of segment point distribution of baselines

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SUMMARY

Additive constant and scale correction are two vital systematic error corrections of total stations; therefore, it is of great significance to increase the measurement precisions of additive constants and scale corrections. This article firstly introduces the most commonly used six-segment comparison method (also called seven-station/pillar method) for calculating the standard deviations of additive constants and scale corrections by the least squares adjustment. Secondly, it studies and analyzes the layout schemes with different distances combination, using an example of a 768 meters field baseline in Gansu Province of China. The total number of layout schemes with different distances combination is 322. Then the precisions of the schemes, which are the standard deviations of additive constants and scale corrections of different layout schemes, are calculated and demonstrated. Finally, the optimized schemes of the field baseline segment arrangement are selected from the 322 ones. The demonstrated results show that the 322 schemes have different standard deviations of additive constants and scale corrections; and thus, the final optimized schemes are those with less standard deviation values.

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1. INTRODUCTION

Electronic Distance Meters (EDMs, including electro-optical distance meters and total stations) have been used extensively in measurements, installations and high-precision monitoring of tunnels, bridges, highway buildings and other large civil projects due to the advantages of their high efficiency, simplicity, convenience in operation, accurate in data processing capability and fast ranging functions. As is well known that every instrument is an individual with specific characteristics which can change with the changes of its internal or/and external factors. So, it is a natural thought to get these factors in order to guarantee the measurement results of the instruments. To obtain this goal EDMs usually need to be calibrated in regular time intervals, or after reparation, or after receiving a rough treatment or a collision, or before being put into field high accuracy surveying (ISO17123-4,2002 and JJG703-2003,2003).

The additive constant and scale correction are two important systematic factors of EDMs. When the additive constant and scale correction obtained from the baseline calibration are statistically salient, they should be applied in subsequent measurements correction. Therefore, it is of great significance to study calibration methods for additive constant and scale correction (Jokela, 2009 and 2010). The six-segment comparison method (JJG703-2003,2003) has been widely used in obtaining the additive constant and scale correction in China, but the baseline layout method is slightly differently used in different calibration centers; and thus, the additive constant and scale correction measured by the same instrument with the six-segment comparison method in different segment points are varying. Thus, how to assess these different results from a baseline is a problem. This paper studies the calibration results using one EDM in the same field baseline with different segment points. It lays out a great number of schemes of different segment point combinations in the same field baseline in Gansu province of China, analyzes their assessment criterion which is the precision of additive constants and scale corrections, and chooses the optimal scheme of segment points on the baseline.

2. DEFINITION OF ADDITIVE CONSTANT AND SCALE CORRECTION

Additive constant is the correction for zero error or index error of EDMs (Rüeger 1996). The additive constant represents fixed errors of the instrument, which is not related to the distance measured. It is mainly caused by electrical delays, differences between the electronic center and the mechanical center of the EDM and differences between the optical and mechanical centers of the reflector (Victoria, 2014). The additive constant is represented by the letter K in this article.

Scale correction is the correction for scale error of EDMs (Rüeger 1996). The scale correction is proportional to the length of the line measured. The scale error is mainly caused by the drift in frequency of the quartz crystal oscillator in the EDMs, phase inhomogeneities, instrument “warm up” effects, and atmospheric refractive index error (Martin 2010). The scale correction is denoted by the letter R in the article.

3. METHODOLOGY OF THE SIX-SEGMENT COMPARISON METHOD.

3.1 Principle

The field baselines have been developed to assist users in verifying the EDMs that work according to the zero error and the scale error listed in the specification given by the instrument manufacturer. The calibration is done by the distance comparison method on an outdoor station-to-station baseline which has been precisely measured in advance (Figure 1). A common six-segment baseline and the possible distances are shown in Figure 2. Measure the distances after the instrument is placed at the one baseline station and the reflector is set up at the forward stations along the baseline successively. Once the measurements for one station are finished, move the instrument and the reflector to the next station along the baseline. All combination distances can be measured in this way (Yang, 2004). The thermometer and barometer readings are recorded on both ends of the measured distance at the start and end of the measurements for each EDM setup. Through the correction of the influence factors such as temperature, humidity, air pressure, based on the principle of least square method, adopt the method of linear regression, lists the error equation, additive and scale corrections can be calculated.

Figure 1 Baseline stations

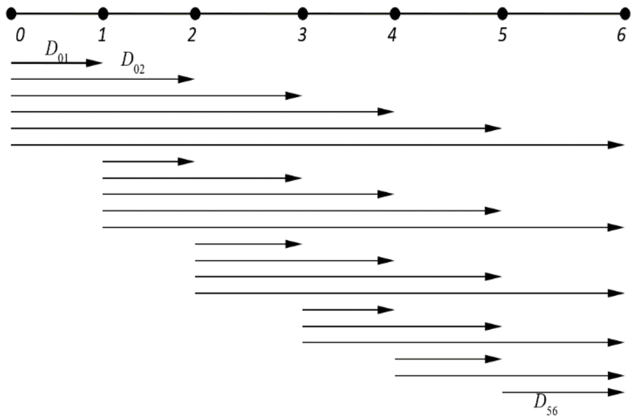

Figure 2 The six-segment field baselines and all possible distances

3.2 Analysis and Calculation

An example of a six-segment baseline with known distances is given in this section. The numbers of all combined distances are 21. 21 measured and true distances are available. The measured distances are meteorologically corrected. The additive constant and the scale correction are solved simultaneously based on a system of linear equations and the least-squares principle (Yang ,2007; 2008).

Assuming an additive constant K, and a scale correction R, measured distances D_{ij} may be corrected by applying the following corrections:

$$D_{ij}^{t} + v_{ij} = D_{ij} + K + R \times D_{ij} \quad (i=0,1,\ldots 5;\ j=1,2,\ldots,6,\ i \neq j) \tag{1}$$

Where, D_{ij}^{t} is the given or "true" distance and v_{ij} is the residual.

The residual can be obtained from the equation (2).

$$v_{ij} = K + R \times D_{ij} - l_{ij} \tag{2}$$

Where $l_{ij} = D_{ij}^t - D_{ij}$

The residual equation can be expressed in matrix form as：

$$V = AX - L \tag{3}$$

Where, $V_{21\times1} = (\, v_{01} \quad v_{02} \quad \cdots \quad v_{56})^T$ is the vector of residuals，

$A_{21\times1} = \begin{pmatrix} 1 & 1 & \cdots & 1 \\ \mathrm{D}_{01} & \mathrm{D}_{02} & \cdots & \mathrm{D}_{56} \end{pmatrix}^T$ is the coefficient matrix,

$X_{2\times1} = (\mathrm{K} \quad \mathrm{R})^\mathrm{T}$ is the vector of parameters, and

$L_{21\times1} = (\, \mathrm{l}_{01} \quad \mathrm{l}_{02} \quad \cdots \quad \mathrm{l}_{56})^T$ is the vector of numeric term.

The least-squares solution of equation (3) is as follows：

$$X = (A^T PA)^{-1} A^T PL \tag{4}$$

All distances are assumed to have equal weights, thus

$$X = \begin{pmatrix} K \\ R \end{pmatrix} = \frac{1}{(\sum\sum D_{ij})^2 - n \cdot \sum\sum D_{ij}^2} \begin{pmatrix} \sum\sum D_{ij} \cdot \sum\sum D_{ij} l_{ij} - \sum\sum D_{ij}^2 \cdot \sum\sum l_{ij} \\ \sum\sum D_{ij} \cdot \sum\sum l_{ij} - n \cdot \sum\sum D_{ij} l_{ij} \end{pmatrix} \tag{5}$$

So far, the additive constant K and scale correction R are solved by the equation 5.

4. PRECISION DETERMINATION

The covariance matrix of parameters $Q = (A^T PA)^{-1}$ is：

$$Q = \begin{pmatrix} Q_{KK} & Q_{KR} \\ Q_{RK} & Q_{RR} \end{pmatrix} = \frac{1}{n \cdot \sum\sum D_{ij}^2 - (\sum\sum D_{ij})^2} \begin{pmatrix} \sum\sum D_{ij}^2 & -\sum\sum D_{ij} \\ -\sum\sum D_{ij} & n \end{pmatrix} \tag{6}$$

Now, the residuals vector V can be got using the equation (3). The standard deviations of a measured distance, additive constant, and scale correction can be derived as follows:

$$m_0 = \sqrt{\frac{V^T V}{n-2}} \tag{7}$$

$$m_K = m_0 \sqrt{Q_{KK}} \tag{8}$$

$$m_R = m_0 \sqrt{Q_{RR}} \tag{9}$$

Where, m_0, m_K and m_R are the standard deviations of a measured distance, additive constant, and scale correction, respectively.

The corresponding 95% confidence intervals are obtained by multiplication with 2.093 (2.093 is obtained from the two-tailed t-distribution table with degree of freedom=21-2=19). If the additive constant and/or scale correction are statistically significant, they should be added into the distances during measuring the distances.

5. CASE STUDY AND DISCUSSION

The study shows that the longer the length of the field base field, the more reliable the scale correction (Yang, 2004). However, it is difficult to find a flat, unobstructed line that is longer than 1km, especially in big cities and mountainous cities. Therefore, it is vital to get an optimization method that can improve the precision of scale correction that is done on limited fields.

The fundamental segment distances of the baseline used in this study in Gansu province are as follows: d_{01}=24m, d_{12}=48m, d_{23}=120m, d_{34}=216m, d_{45}=96m, d_{56}=264m. The total length is

768m.The distances are multiples of 24m. If segment points are changed, for example, d_{01}=48m, d_{12}=24m, d_{23}=120m, d_{34}=216m, d_{45}=120m, d_{56}=220m, numerous optional schemes can be generated. Therefore, it is necessary to get a couple of optimized schemes.

In order to study the effect of baseline segment point distribution, all schemes with different segment points are enumerated firstly. The optimal distribution mode was obtained by changing the distribution position of each segment point without changing the total length of the baselines.

The arrangements with each of which has six numerical values are obtained using a sorting algorithm. Then the same combinations are deleted, and there are 322 combinations left. According to the coefficients of the scale corrections, some combinations are listed in Table 1 and the 109th combination is the existing baseline field distribution in Gansu province.

Combined with table 1, the following results can be analyzed:

Table 1 Comparison of the coefficients of scale corrections with the same length and different segments points

Scheme	Baseline length (km)	Segment baseline length(m)						Q_{KK}	Q_{RR}
		d_{01}	d_{12}	d_{23}	d_{34}	d_{45}	d_{56}		
1	0.768	24	96	216	264	120	48	0.174	0.796
2	**0.768**	**24**	**48**	**120**	**264**	**216**	**96**	**0.163**	**0.800**
3	0.768	24	120	264	216	96	48	0.174	0.800
4	0.768	24	96	264	216	120	48	0.174	0.800
5	0.768	24	120	216	264	96	48	0.174	0.801
6	**0.768**	**24**	**48**	**120**	**216**	**264**	**96**	**0.161**	**0.806**

7	0.768	24	48	96	264	216	120	0.160	0.809
8	0.768	24	48	96	216	264	120	0.157	0.810
…	…	…	…	…	…	…	…	…	…
109	**0.768**	**24**	**48**	**120**	**216**	**96**	**264**	**0.162**	**0.972**
…	…	…	…	…	…	…	…	…	…
319	0.768	216	120	48	96	24	264	0.166	1.425
320	0.768	216	96	24	120	48	264	0.166	1.428
321	0.768	216	48	96	120	24	264	0.172	1.434
322	0.768	216	96	48	120	24	264	0.169	1.437

From Table 1, it can be seen that the change of the correlation coefficients (Q_{KK}) of the additive constants are generally little, while the correlation coefficient (Q_{RR}) of the scale correction varies greatly. Thus, a reasonable conclusion is that the distribution of segment points of the baseline has great influence on the scale correction. Therefore, it can be considered as the main factor for evaluating optimal solutions in baseline design.

As can be seen from the top eight schemes in Table 1, the correlation coefficients of scale corrections calculated by the distribution method are relatively less if the longer distances are placed in the middle, and the shorter distances are placed on both ends as shown in Figure 3. That is, the precision of the scale correction is higher. From the last four schemes, the correlation coefficients of scale corrections are relatively greater when the distribution of the distances is arranged as long-short-long-long-short-long (Figure 4). Table 1 shows that the second and the sixth scheme are the better ones for the Gansu baseline design since the precision of additive constants and scale corrections are higher.

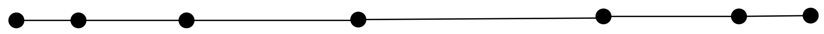

Figure 3 Segment points are dense on both ends and sparse in the middle of the baseline

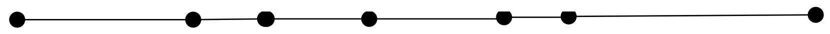

Figure 4 Segment points are sparse on both ends and dense in the middle of the baseline

6. CONCLUSION

The results obtained from the six-segment baseline method are used to get the additive constant and scale correction and determine the performance and reliability of the EDMs, where baselines play important roles. The case of Gansu baseline shows that the different distributions of the segment points of a baseline have different calibration precisions. For a certain length of the baseline, the scheme whose segment points distributed dense on both ends and sparse in the middle on the baseline is the best one, which is most useful in baseline scheme design.

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