DOI: 10.32347/2076-815X.2022.80.261-274
УДК 528.061
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ON THE DEVELOPMENT OF THE ALGORITHM FOR DETERMINATION OF STADIA CONSTANT OF ELECTRONIC TACHOMETERS

An algorithm for determining the stadia constant of the rangefinder is developed and tested. This algorithm is based on the generalized reduced gradient (GRG) method with consistent use of criteria of minimizing the maximum deviation and minimizing the total sum of squares of deviations. There were some stages of the research. First, we carried out 200 measurements with equal accuracy by a SOUTH NTS-350 electronic tachometer. The statistical processing of measurement results enabled specification of the optimal number of measurements for the device taking into account the dependence of the correlation values of instrumental and random errors. Having determined the optimal number of measurements, we continued the study of the proposed method of calculating the stadia constant of electronic tachometers. According to the data obtained during the measurement of the range of the target, which consisted of four points, conditional equations were compiled. These conditional equations are based on the relationships between the length of the measured target and its segments in all combinations, taking into account the stadia constant of the rangefinder. Due to the large number of measurements, the solution of such system of equations is to find the minimum of some function for determining the errors of the measured distances. Our methodology is based on the use of the Lagrange multiplier method in finding the solution of a nonlinear programming problem, which in most software resources is called the Nonlinear Generalized Consolidated Gradient (GRG). The essence of this solution is to find a conditional local extremum. In this case, it is most appropriate to consistently use the criteria of minimizing the maximum deviation and minimizing the total sum of squares of deviations. The method of minimizing the maximum deviation makes it possible to reject gross errors in the measured values. The following minimization of the total sum of squares of deviations will allow to minimize random errors of the measured distances, as the selected samples are subject to the normal distribution law. Thus, the most probable value of the constant correction of the rangefinder and lengths of the measured target and its segments for all possible combinations has been obtained.

Keywords: electronic total station; measurement errors; minimization of squares of deviations; error theory; equivalent measurements.

Introduction. Currently, rangefinder technology, particularly electronic rangefinders, is widely used in almost all types of surveying and various studies [14, 17]. One of the areas of electronic tachometer application is engineering structures deformations monitoring with periodic control of geometric parameters. However, the problems in this area are challenging to solve and require high measurement accuracy [7, 15]. To provide the required accuracy of measurement results, it is necessary to minimize the impact of systematic errors that various factors may cause. In particular, the mismatch of the electronic rangefinder – reflector axes of rotation [6, 8]. A constant correction (ν) for most modern tacheometers is set to zero [5]. However, its value may change over time due to device operation. Therefore, to provide high accuracy and obtain reliable results of electronic tacheometer performance, this systematic error should be considered. Classically, electronic rangefinders' constant correction is determined on reference geodetic polygons [5, 9, 18] by comparing the measured values of tensor quantities with their reference values. However, in Ukraine, there are not enough geodetic reference landfills and metrological laboratories to provide rapid and high-quality control of rangefinder equipment. All this justifies the need to improve existing and develop new methods for determining the stadia constant correction of an electronic rangefinder.

The object of research is high-precision measurement and monitoring of linear engineering structures in real atmospheric conditions.

The subject of research is methods and technological solutions for determining the stadia constant correction of electronic rangefinder using modern geodetic methods.

This work aims to develop a new method for processing the research results while calculating the electronic rangefinders stadia constant correction by nonlinear programming methods.

Achieving this goal involves solving the following research objectives:

1) development of recommendations for improving the accuracy and efficiency of stadia constant correction determination of electronic rangefinder by providing the optimal number of measurements;

2) development of a method for calculating the stadia constant correction of electronic rangefinders by nonlinear programming methods with the possibility of rejecting gross errors;

3) testing of the proposed technological solutions on the industrial site.

The scientific novelty of the obtained research results: for the first time, it is proposed to use the generalized reduced gradient (GRG) method with consistent use of the criteria of minimizing the maximum deviation and minimizing the total sum of squares of deviations to determine the stadia constant correction of rangefinders.

The practical significance of the research results:
1) possibility to conduct metrological control of rangefinders on the industrial site before performing high-precision engineering and geodetic works;
2) reduction of range-finding measurement time by the way of definition of optimal quantity of necessary measurements for the device;
3) increase the accuracy of determining the constant correction of the rangefinder by at least 10% compared to the known method of correlates.

Analysis of recent research and publications. Currently, there are several [1, 2] classical methods for determining the stadia constant correction by measuring the known distance on a geodetic reference basis. The authors of the first study [4] measured 300-500 m long for the reference base. The authors of the second study [7] measured the distances of known length within the phase cycle. The third study – measured some primary data, the lengths of which were measured by another verified device with the required accuracy [5]. These methods envisage stadia constant correction of electronic rangefinder calculation as the difference between the known distance and measured using the studied electronic rangefinder. The disadvantage of the above methods is the need for research on a geodetic reference basis, the accuracy of which should be 2 · 10-6 m, the impact of errors in the centering of the rangefinder and reflector, destabilizing factors such as atmospheric conditions. However, there may not be a reference base near the site of high-precision engineering and geodetic works, and creating such a landfill in the short term is impossible. It is known that the number of reference geodetic landfills in Ukraine is insufficient [10, 11]. Such landfills operate in Kyiv, Kharkiv, Vinnytsia, Crimea, Mykolaiv, Lviv region [9], and on the territory of Kolomyia airport in the Ivano-Frankivsk region (certificate of state metrological certification of Ukrmetrteststandart No 23-0054 dated 28.05.2015). An alternative to these methods can be considered techniques based on linear, angular measurements [3]. The advantages of these methods are the high accuracy of the results and the ability to perform measurements directly on the site. Still, when processing the results in such a network, there are difficulties in choosing weights for linear and angular measurements. In our opinion, the most effective and easy to implement is the measurement of segments of the target in all combinations [6, 13]. The main advantages of this method are ease of implementation, no need for additional equipment, and speed. There are no recommendations for processing the results of such a study.

The main material. We assume that all the obtained values has the equal accuracy, because all measurement results are homogeneous, obtained by the same instrument and method of measurements under the same meteorological conditions.

Thus, the total measurement error (δ) can be represented as the sum of the systematic (ν) and random component (Δ)

$$\delta = \nu + \Delta . \quad (1)$$

To increase the accuracy of the obtained results, we excluded the random component of the device error from the results of the measured distances. Considering the property of compensating for equal errors, and the property of simple arithmetic mean, it can be argued that the arithmetic mean will be free from random errors. These conditions allow us to write:

$$\Delta_i \doteq \delta_i - \frac{\ldots}{n} - \nu \quad (2)$$

In practice, the number of measurements is limited, so to obtain reliable results it is necessary to check whether the values obtained are subject to the normal distribution law, for which the density function of the distribution of random variables is expressed by the formula

$$\Phi(X) = \frac{1}{\sqrt{2\ldots}} \exp^{-\frac{\ldots}{2\sigma^2}} . \quad (3)$$

where m – the mathematical expectation;

σ – the standard deviation (σ^2– variance).

According to the theory of errors, if random errors obtained from equilibrium measurements obey the normal Gaussian distribution law, then the properties described above apply to them. The use of the apparatus of mathematical statistics is difficult, so an alternative to using the function of density distribution of random variables can be used rule of 3σ:

$$P(|X - a| \geq 3\sigma) \rightarrow 0 . \quad (4)$$

The rule of 3σ should be used to verify the obtained measurements for compliance with the normal distribution law: if the distribution law of the measured values is unknown, but the condition specified in this rule is met, then we can assume that the random variable is normally distributed.

The probability that the deviation in absolute value will be less than three times the standard deviation is 0.9973.

The theory of the Gaussian method shows that an infinite increase in the number of measurements does not give a noticeable increase in accuracy [12, 16]. Therefore, it is not advisable, and sometimes not possible to perform a large number of measurements to determine a single value, in our case, the distance. The number of required measurements is determined by the ratio of the instrumental (for electronic rangefinder SOUTH NTS-350 m = 2 mm + 2 mm per 1 km) and random errors (Δ).

In this case, the efficiency of minimizing the squares of deviations is maintained. To determine the standard deviation, we use the known formula

$$\sigma(\hat{\delta}) = \frac{1}{n}\sqrt{\sum_{i=1}^{n} D_{i,j}} \quad . \tag{5}$$

where, $D_{i,j}$ is the covariance matrix of measurement errors according to the formula

$$D_{ij} = \begin{cases} \sigma, & i = j \\ 1, \; 2 \; . \; . \; . & [illegible] \end{cases} \tag{6}$$

To determine the optimal number of measurements of one quantity, consider the effect of correlation between measurement errors. As a result of measurements, 200 equivalent measurements were obtained and their root-mean-square errors (σ) were calculated. Calculate the correlation between measurement errors, the constant correlation coefficient is k = 0.8834.

Fig. 1 shows a graph of the relationship between the number of n measurements.

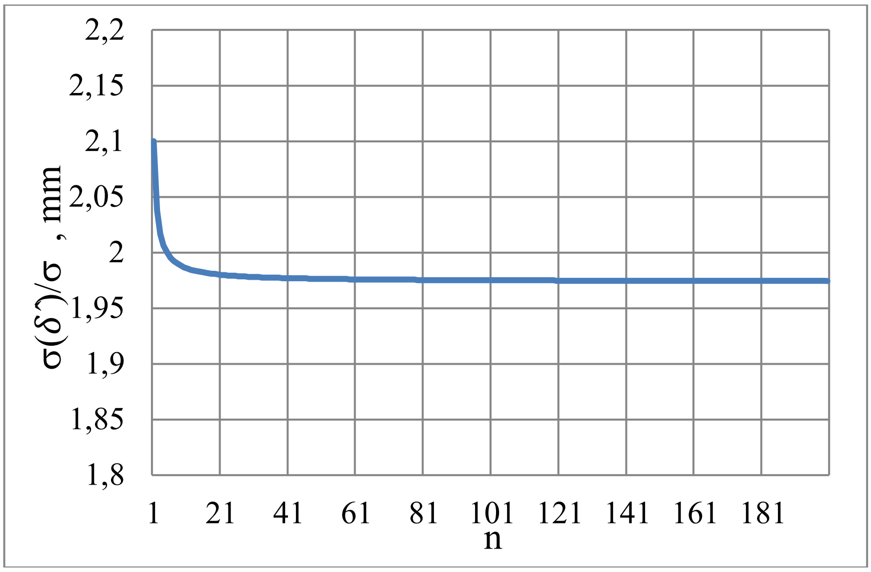


Fig. 1. Dependence of the standard deviation of the arithmetic mean on the number of measurements

The figure shows that the considered function takes smaller values, approaching its minimum with the increasing number of measurements n, the considered function takes smaller values, approaching its minimum. However, starting with a number of measurements (n = 40), the decrease in error becomes insignificant and further increase in the number of measurements can be considered practically unjustified. For a more detailed assessment of the obtained sample, we examine the effect of unaccounted for correlation between measurements on the assessment of accuracy.

Calculate the root mean square error (MSE) according to the Bessel formula to further minimize the impact of systematic errors.

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{n}(S_i - S_{aver})^2}{n-1}} \qquad (7)$$

Having obtained the values of MSE for different number of measurements in the range of one sample, consisting of 40 equivalent distance measurements, graphically represent the effect of unaccounted for correlation for this case.

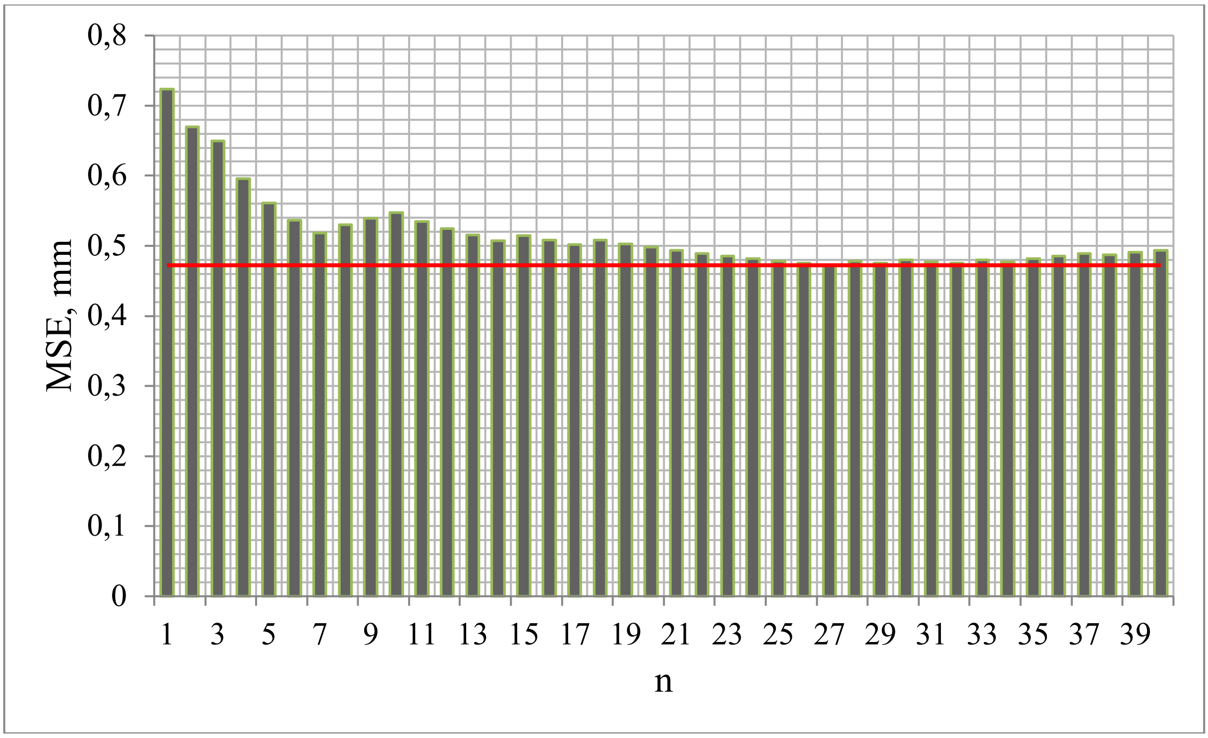


Fig.2. Dependence of the influence of the number of measurements on the MSE

Based on the obtained results, which are illustrated graphically (Fig. 2), MSE decreased with increasing number of measurements. However, after the thirtieth value (MSE=0.472198) began to grow monotonously. In this case, at n≥30, increasing the number of measurements is harmful in terms of ensuring the optimal number of measurements.

According to the obtained results, it can be stated that it is impossible to completely get rid of systematic errors, some systematic errors caused by minor changes in measurement conditions remain. This feature is accompanied by a slight correlation between the measured distances, which in turn leads to the accumulation of systematic errors and deterioration of the results. Unreasonable increase in the number of measurements leads to an increase in the time interval of measurements and loss of accuracy of the desired parameter (distance).

Having determined the optimal sample size, we will continue the study of the proposed method of calculating the constant correction of the rangefinder (ν) according to the data obtained during experimental studies on the designed target. Two stands at a distance of 125 m from each other were installed on the section with concrete cover without significant height differences. The electronic rangefinder and reflector are installed at items 1 and 4, respectively (see Fig. 3). After that, in the line of sight 1 4 at distances of 41 m and 74 m set tripods in points 2 and 3, so the line is divided into three parts. Each distance was measured thirty times, the optimal number of measurements for this electronic rangefinder was proved above. The study was performed in the morning in sunny weather at a temperature of 14˚C, pressure 737 mm Hg. Art.

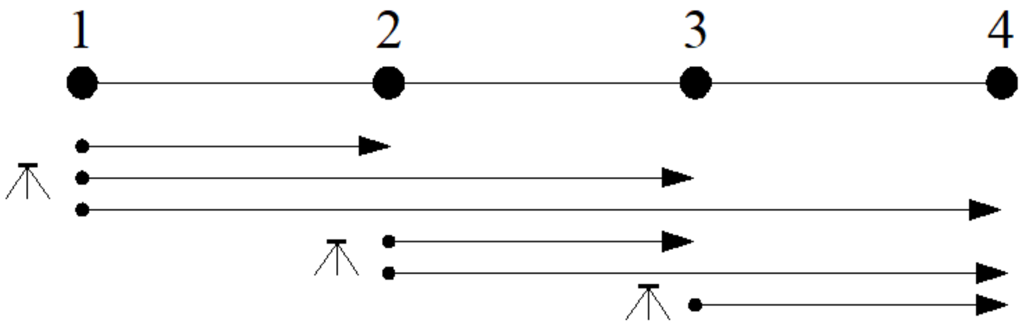


Fig.3. A typical scheme of the creative method of determining the rangefinder constant

Transferring the rangefinder between the tripods according to the following scheme (see Fig.3) measure all possible distances:

1) from the first station measure distances: S_{1-2}. S_{1-3}. S_{1-4};

2) distances are measured from the second station: S_{2-3}. S_{2-4};

3) distances are measured from the third station: S_{3-4}.

The average values of the measured distances and their variances are given in table 1.

Table 1.

The results of measurements of the distances of the laid target

	The average distance of the segment, m	**SME, mm**
S_{1-2}	41.5434	0.0156
S_{1-3}	74.3465	0.0159
S_{1-4}	125.0361	0.0113
S_{2-3}	32.8	0.0069
S_{2-4}	83.4892	0.0132
S_{3-4}	50.687	0.0069

Considering the peculiarities of the above scheme of measurements (Fig. 3), we can make the following equations to determine the correction:

$$\begin{cases} S_{1-3}^{meas.} - \nu + S_{3-4}^{meas.} - \nu - (S_{1-4}^{meas.} - \nu) = 0 \\ S_{2-4}^{meas.} - \nu + S_{1-2}^{meas.} - \nu - (S_{1-4}^{meas.} + \nu) = 0 \\ S_{1-2}^{meas.} - \nu + S_{2-3}^{meas.} - \nu + S_{3-4}^{meas.} - \nu - (S_{1-4}^{meas.} - \nu) = 0 \\ S_{1-2}^{meas.} - \nu + S_{2-3}^{meas.} - \nu - (S_{1-3}^{meas.} - \nu) = 0 \\ S_{2-3}^{meas.} - \nu + S_{3-4}^{meas.} - \nu - (S_{2-4}^{meas.} + \nu) = 0 \end{cases} . \quad 8)$$

The first three dependences are made given that the sum of the true lengths of the line segments, taking into account the constant correction of the rangefinder, must be equal to the balanced length of the whole line S1 4. The other two dependences are made on the same principle, however, for intermediate distances S1 3 and S2 4 in accordance. Solving the above system of conditional equations, we obtain the values of the constant correction of the rangefinder, approximating the dimensions of the target and its segments, which will be consistent in all possible combinations.

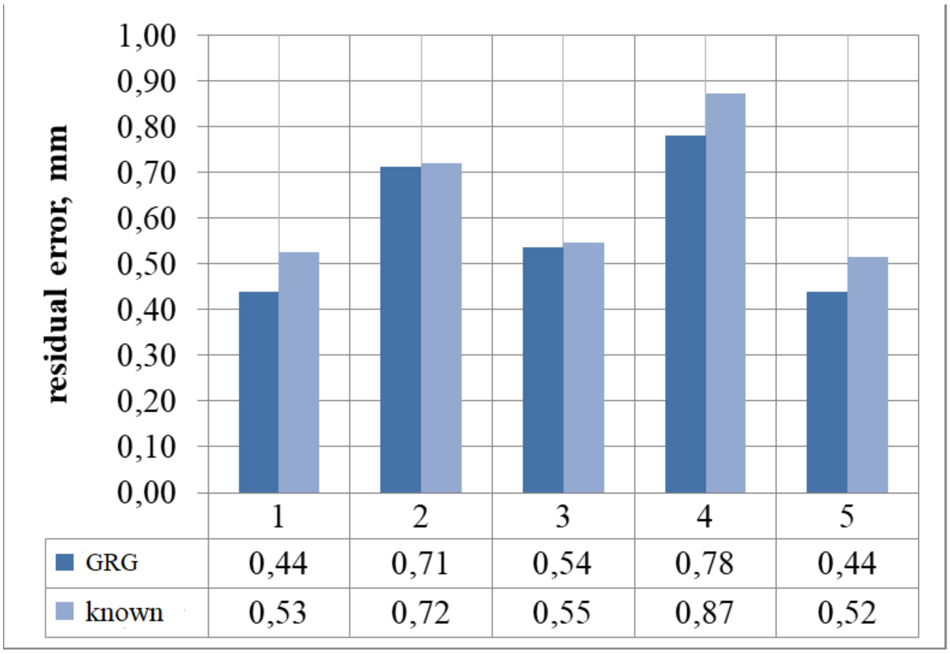
Our methodology is based on the use of the Lagrange multiplier method in finding the solution of a nonlinear programming problem, which in most software resources is called the Nonlinear Generalized Consolidated Gradient (GRG). The essence of this solution is to find a conditional local extremum. In this case, it is most appropriate to consistently use the criteria of minimizing the maximum deviation and minimizing the total sum of squares of deviations (least squares method). The method of minimizing the maximum deviation makes it possible to reject gross errors in the measured values. The following minimization of the total sum of squares of deviations (9) will allow to minimize random errors of the measured distances, as the selected samples are subject to the normal distribution law:

$$\sum_{i=1}^{n} (S_{i,j}^{вим} - S_{i,j}^{іст} - \nu)^2 \rightarrow \min . \quad (9)$$

Thus, we obtain the most probable value of the constant correction of the rangefinder, the value of the lengths of the measured target and its segments, which will be consistent in all possible combinations.

Research results and their discussion. In order to adequately assess the quality of the algorithm, the constant correction of the rangefinder is additionally calculated by the known correlate method. After that, the result obtained by the proposed method of nonlinear programming and the known correlate method is substituted into each of the equations of system (8). Figure 4 illustrates the results of the calculations.

On the y-axis, the residual error is postponed after taking into account the constant correction of the rangefinder; on the abscissa - the ordinal number of the equation from the system (14). The numbers below the histogram show how much the proposed method increases the accuracy of the known.



19.6% 14% 9.9% 11.8% 17.6%

Fig.4. Comparison of the accuracy of the proposed method with the known ones

According to the analysis of histogram data, it can be stated that the proposed technological solutions allow increasing the accuracy of balancing the value of the constant correction of the rangefinder, the length of the measured field and its segments compared to the known correlate method by at least 10%.

Let's evaluate the accuracy of the obtained results of the proposed algorithm. To obtain MSE balanced lengths of the target and its segments, the calculation was performed by the formula:

$$m = \sqrt{\frac{\sum_{i=1} (S_{ij} - S_{ik} - S_{kj})}{n}} = 0.6 \qquad (10)$$

The accuracy of the balanced approximate values of the length of the line and its segments is almost three times higher than declared by the manufacturer of the UPC measurement of the lengths of the lines of the investigated rangefinder SOUTH NTS-350.

Conclusion

1. The advantage of the developed algorithm for processing the results of research on the constant correction of electronic rangefinders over the existing ones is:

- possibility to carry out metrological control of rangefinders practically on the industrial site, before performance of high-precision engineering and geodetic works without considerable time and material expenses in comparison with researches on the reference geodetic range;

- reducing the time of rangefinders measurements by determining the optimal number of required measurements for the device, taking into account the influence of the correlation between the values of instrumental and random errors (Δ);

- no need for additional expensive devices.

2. The algorithm of processing the results of calculating the constant correction of the rangefinder by measuring the length of the target and its segments in all combinations is theoretically substantiated and tested. It is proposed to control the number of required measurements of one distance based on the influence of the correlation between the values of instrumental and random errors. The value of the distance correction of the rangefinder was found by the method of nonlinear programming with consistent use of the criteria of minimizing the maximum deviation and minimizing the total sum of the squares of the deviations (least squares method). At the same time, the obtained value of the constant correction of the rangefinder is consistent with the value of the lengths of the measured target and its segments in all possible combinations.

3. Experimental testing of the developed algorithm, the results of which confirm the effectiveness of the proposed technological solutions and show an increase in the accuracy of the results by at least 10% compared to the known method of correlates.

4. The example of the SOUTH NTS-350 rangefinder study shows that the accuracy of the balanced approximated values of the line lengths and its segments is almost three times higher than the line length measurements declared by the SME manufacturer.

REFERENCES

1. Baran P.I. Inzhenerna heodeziia / Petro Ivanovych Baran. – Kyiv: PAT «VIPOL», 2012. – 618 s. {in Ukrainian}

2. Borovyi V.O. Vysokotochni inzhenerno-heodezychni vymiriuvannia / V. Borovyi, V. Burachek. – Vinnytsia: TOV «Nilan-LTD», 2017. – 236 s. {in Ukrainian}

3. Vyznachennia tochnosti vidkhylennia polozhennia blyzkostvornoi tochky za dopomohoiu elektronnoho takheometra / [K.O. Burak, M.Ya. Hrynishak, V.M. Kovtun ta in.]. // Visnyk heodezii ta kartohrafii. – 2012. – S. 15–17. {in Ukrainian}

4. Kolomiiets L.V. Analiz metrolohichnoho zabezpechennia heodezychnykh zasobiv vymiriuvalnoi tekhniky / L.V. Kolomiiets, K.O. Podostroiets // Visnyk Inzhenernoi Akademii Ukrainy. – 2010. – № 1. – S. 253-255. {in Ukrainian}

5. Kolomiiets L.V. Metrolohycheskyi kontrol takheometrov / L.V. Kolomyets, K.A. Podostroets // Kompetentnost: nauchno-tekhnycheskyi zhurnal. – 2014. – № 3/114. – S. 36–40. {in Ukrainian}

6. Kostetska Ya.M. Opratsiuvannia rezultativ doslidzhennia pryladovoi popravky takheometriv za dopomohoiu vymiriuvannia vidrizkiv linii u vsikh kombinatsiiakh / Ya. Kostetska, V. Bletskan // Heodeziia i heodynamika. – 2011. – Vyp. II(22). – S. 109–111. {in Ukrainian}

7. Kuzmenko Yu., Samoilenko O. Opratsiuvannia za metodom naimenshykh kvadrativ rezultativ vymiriuvan za kliuchovykh, rehionalnykh ta dodatkovykh zviren etaloniv. Metrolohiia ta prylady. Kharkiv: VKF “Favor”, 2018, № 2 {in Ukrainian}

8. Litynskyi. V.O. Cposib vymiriuvannia vzirtsevoho bazysa 2-ho rozriadu dlia etalonuvannia elektronnykh takheometriv / V. Litynskyi, A. Vivat, S. Perii, S. Litynskyi // Heodeziia, kartohrafiia i aerofotoznimannia. – Lviv 2015. - Vyp. 81.- S. 59-65{in Ukrainian}

9. Podostroiets K.O. Alternatyvnyi shliakh rozvytku metrolohichnoho zabezpechennia zasobiv vymiriuvalnoi tekhniky dlia vyznachennia velykykh liniinykh rozmiriv / L.V. Kolomiiets, K.O. Podostroiets // Viiskova osvita i nauka: sohodennia ta maibutnie: tez. dop. VII Mizhnarodnoi nauk.-prakt. konf., 24 – 25 lystopada 2011 r., – Kyiv, VIKNU, 2011. – s.47-48. {in Ukrainian}

10. Trevoho I.S., Etalonnyi heodezychnyi bazys oryhinalnoi konstruktsii / I. S. Trevoho, O. Denysov, I. Tsiupak, V. Heher., V. Tymchuk // Suchasni dosiahnennia heodezychnoi nauky i vyrobnytstva. Lviv: LihaPres, 2010, Vyp. 1(19), S. 43–49. {in Ukrainian}

11. Trevoho I.S., Osoblyvosti metrolohichnoi atestatsii etalonnykh heodezychnykh bazysiv / I.S. Trevoho, I.M. Tsiupak// Suchasni dosiahnennia heodezychnoi nauky ta vyrobnytstva: zb. nauk. prats. Lviv, 2014, Vyp. I (27), S. 29–33. {in Ukrainian}

12. Tomashevskyi O.V. Kompiuterni tekhnolohii statystychnoi obrobky danykh navch. posib. / O.V. Tomashevskyi, V.P. Rysikov. ZNTU, 2015. – 175 s. {in Ukrainian}

13. Braun, J., Dvořáček, F., Štroner, M. Absolute Baseline for Testing of Electronic Distance Meters. Geoinformatics FCE CTU, 2014, 12, 28-33. {in English}

14. Cox, M.G. The evaluation of key comparison data: An introduction. Metrologia, 2002, 39(6), 587. {in English}

15. JCGM 200:2012. International vocabulary of metrology – Basic and general concepts and associated terms (VIM). Joint Committee for Guides in Metrology. Режим доступу: https://www.bipm.org/utils/ common/documents/-jcgm/JCGM_200_2012_E.pdf. {in English}

16. JCGM 102:2011 Evaluation of measurement data – Supplement 2 to the "Guide to the expression of uncertainty in measurement" Extension to any number of output quantities. Joint Committee for Guides in Metrology. Режим доступу: https://www.bipm.org/utils/common/documents/- jcgm/JCGM_102_2011_E.pdf. {in English}

17. Jokela, J., Häkli, P., Kugler, R., Skorpil, H., Matus, M., & Poutanen, M. (2010, April). Calibration of the BEV geodetic baseline. In FIG Congress 2010 (pp. 2873-87). {in English}

18. JRP SIB 60 Metrology for long distance surveying. Режим доступу: http://www. ptb. de/emrp/sib60-home. html. {in English}

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ДО ПИТАННЯ РОЗРОБЛЕННЯ АЛГОРИТМУ ВИЗНАЧЕННЯ ПРИЛАДОВОЇ ПОПРАВКИ ЕЛЕКТРОННИХ ТАХЕОМЕТРІВ

Розроблено та апробовано алгоритм визначення постійної поправки віддалеміра в основі якого є метод узагальненого зведеного градієнта (GRG) з послідовним використанням критеріїв мінімізації максимального відхилення та мінімізації повної суми квадратів відхилень. Дослідження проводились у декілька етапів. Спочатку за допомогою електронного тахеометра SOUTH NTS-350 було одержано 200 рівноточних вимірів. За допомогою статистичного опрацювання результатів вимірювань було встановлено оптимальну кількість вимірювань для приладу із врахуванням залежності кореляційної величинами інструментальної і випадкової похибок. Визначивши оптимальну кількість вимірів, було продовжено дослідження запропонованої методики розрахунку постійної поправки віддалеміра. За даними, одержаними під час вимірювання віддалей створу, який складався із чотирьох пунктів, було складено умовні рівняння. В основі яких лежать залежності між довжиною виміряного створу та його відрізків у всіх комбінаціях з урахуванням постійної поправки віддалеміра. За наявністю великої кількості вимірювань розв'язання такої системи рівнянь полягає у знаходженні мінімуму деякої функції визначення похибок виміряних віддалей. Розроблена методика базується на використанні

методу множників Лагранжа при знаходженні розв'язку задачі нелінійного програмування, яка у більшості програмних ресурсів має назву - Нелінійний метод узагальненого зведеного градієнта (GRG). Суть даного рішення полягає у знаходженні умовного локального екстремуму. При цьому, найбільш доцільними є послідовне використання критеріїв мінімізації максимального відхилення та мінімізації повної суми квадратів відхилень. Метод мінімізації максимального відхилення дає можливість відбракування грубих помилок у виміряних значеннях. Наступна мінімізація повної суми квадратів відхилень дасть можливість мінімізувати випадкові похибки виміряних віддалей, оскільки обрані вибірки піддаються нормальному закону розподілу. Таким чином, отримано найімовірніше значення постійної поправки віддалеміра, значення довжин виміряного створу та його відрізків, які будуть узгодженими у всіх можливих комбінаціях.

Ключові слова: електронний тахеометр; похибки вимірювань; мінімізація квадратів відхилень; теорія похибок; рівноточні виміри.

ЛІТЕРАТУРА

1. Баран П.І. Інженерна геодезія / Петро Іванович Баран. – Київ: ПАТ «ВІПОЛ», 2012. – 618 с.

2. Боровий В.О. Високоточні інженерно-геодезичні вимірювання / В. Боровий, В. Бурачек. – Вінниця: ТОВ «Нілан-ЛТД», 2017. – 236 с.

3. Визначення точності відхилення положення близькостворної точки за допомогою електронного тахеометра / [К.О. Бурак, М.Я. Гринішак, В.М. Ковтун та ін.]. // Вісник геодезії та картографії. – 2012. – С. 15–17.

4. Коломієць Л.В. Аналіз метрологічного забезпечення геодезичних засобів вимірювальної техніки / Л.В. Коломієць, К.О. Подостроєць // Вісник Інженерної Академії України. – 2010. – № 1. – С. 253-255.

5. Коломієць Л.В. Метрологический контроль тахеометров / Л.В. Коломиец, К.А. Подостроец // Компетентность: научно-технический журнал. – 2014. – № 3/114. – С. 36–40.

6. Костецька Я.М. Опрацювання результатів дослідження приладової поправки тахеометрів за допомогою вимірювання відрізків лінії у всіх комбінаціях / Я. Костецька, В. Блецкан // Геодезія і геодинаміка. – 2011. – Вип. ІІ(22). – С. 109–111.

7. Кузьменко Ю., Самойленко О. Опрацювання за методом найменших квадратів результатів вимірювань за ключових, регіональних та додаткових звірень еталонів. Метрологія та прилади. Харків: ВКФ "Фавор", 2018, № 2

8. Літинський. В.О. Спосіб вимірювання взірцевого базиса 2-го розряду для еталонування електронних тахеометрів / В. Літинський, А. Віват, С. Перій, С. Літинський // Геодезія, картографія і аерофотознімання. – Львів 2015. - Вип. 81.- С. 59-65

9. Подостроєць К.О. Альтернативний шлях розвитку метрологічного забезпечення засобів вимірювальної техніки для визначення великих лінійних розмірів / Л.В. Коломієць, К.О. Подостроєць // Військова освіта і наука: сьогодення та майбутнє: тез. доп. VII Міжнародної наук.-практ. конф., 24 – 25 листопада 2011 р., – Київ, ВІКНУ, 2011. – с.47-48.

10. Тревого І.С., Еталонний геодезичний базис оригінальної конструкції / І. . Тревого, О. Денисов, І. Цюпак, В. Гегер., В. Тимчук // Сучасні досягнення геодезичної науки і виробництва. Львів: ЛігаПрес, 2010, Вип. 1(19), С. 43–49.

11. Тревого І.С., Особливості метрологічної атестації еталонних геодезичних базисів / І.С. Тревого, І.М. Цюпак// Сучасні досягнення геодезичної науки та виробництва: зб. наук. праць. Львів, 2014, Вип. I (27), С. 29–33.

12. Томашевський О.В. Комп’ютерні технології статистичної обробки даних навч. посіб. / О.В. Томашевський, В. П. Рисіков. ЗНТУ, 2015. – 175 с.

13. Braun, J., Dvořáček, F., Štroner, M. Absolute Baseline for Testing of Electronic Distance Meters. Geoinformatics FCE CTU, 2014, 12, 28-33

14. Cox, M.G. The evaluation of key comparison data: An introduction. Metrologia, 2002, 39(6), 587.

15. JCGM 200:2012. International vocabulary of metrology – Basic and general concepts and associated terms (VIM). Joint Committee for Guides in Metrology. Режим доступу: https://www.bipm.org/utils/ common/documents/-jcgm/JCGM_200_2012_E.pdf

16. JCGM 102:2011 Evaluation of measurement data – Supplement 2 to the “Guide to the expression of uncertainty in measurement” Extension to any number of output quantities. Joint Committee for Guides in Metrology. Режим доступу: https://www.bipm.org/utils/common/documents/- jcgm/JCGM_102_2011_E.pdf

17. Jokela, J., Häkli, P., Kugler, R., Skorpil, H., Matus, M., & Poutanen, M. (2010, April). Calibration of the BEV geodetic baseline. In FIG Congress 2010 (pp. 2873-87).

18. JRP SIB 60 Metrology for long distance surveying. Режим доступу: http://www. ptb. de/emrp/sib60-home. html