Accuracy of Reflectorless Technology for Distance Measurements in Practice

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Abstract: Utilization of reflectorless technology for distance measurements is very useful in surveying practice and improves efficiency of geodetic measurements. Some experience, however, has shown that measurements of distance by utilization of reflectorless technology could differ more than expected. In this research, the main aim was to find out if the accuracy and reliability of measured distances by reflectorless technology are on the acceptable level for determination position of the points i.e. their coordinates. Common characteristic of investigated accuracy of distances obtained by reflectorless technology in literature is careful design of experiments and controlled conditions, but in practice it is not the case. That is the reason for designing the experiment, which reflects the conditions as near as possible to the real conditions in practice. The surfaces for measurement were divided into two groups: regular and irregular and differences of distances obtained by reflectorless measurements were investigated in the case of manual and automated sighting. Obtained results show that distances, when measured by using reflectorless technology in only one position of telescope, could not be reliable while the average value of measurements obtained in two positions of telescope are of higher accuracy especially for the longer distances.

Keywords: distance accuracy; reflectorless; repeated measurements

1 INTRODUCTION

Some experiences in distance measurements have shown that utilization of reflectorless mode in two positions of telescope resulted in differences greater than expected. The accuracy of reflectorless distance measurement is declared mainly with $\sigma_d = 2 + 2$ ppm [1, 2], or $\sigma_d = 3 + 2$ ppm [3] but results obtained in practice exceeded these values significantly. This fact inspired the idea for researching the phenomenon of distance differences obtained in two positions of total stations' telescope by reflectorless technology. The practical importance of this research stems from the fact the utilization of reflectorless mode of distance measurements is very useful in engineering measurements and its reliability might be crucial for efficiency in solving certain engineering problems.

The accuracy and reliability of reflectorless distances measurement were the issue of numerous researches because of its importance for efficiency in solving geodetic tasks. In paper [4] the accuracy of long-range reflectorless distance measurement was evaluated depending on materials of targets, target size and different incidence angles. Obtained results showed the maximum differences for concrete at incidence angle of 60º in the range from −15 mm to +1mm, and differences increase with length of measured distances (the range of measured distances were from 100 m to 600 m). In paper [5] the accuracy of reflectorless measurements dependence on reflectance of targets was tested. Despite the conclusion that reflectance did not affect the accuracy significantly some limitations of technology suggest that each specific case requires testing accuracy of reflectorless distance measurements.

The concepts of precision, accuracy and reliability might be also suitable for estimating the quality of reflectorless measurements of distances. The accuracy could be defined as the degree of closeness of an observation to the "true" value while the precision is defined as the degree of closeness and consistency of repeated measurements of the same quantity to each other [6]. The concept of reliability in geodesy is connected with geodetic networks, i.e. with the influence of undetected outliers on the model (external reliability) and with

maximum undetectable error in the model [7]. The accuracy, precision and reliability with respect of the different errors were researched and conclusion was that "there remains a number of questions in regard of specific variables" [8].

Research of different surfaces made from different materials and painted with different colour influences resulted with significantly less value of accuracy than specified for used instrument [9]. The evaluation of reflectorless total station accuracy leads to conclusion that reflectorless and prismatic options converge for the short distances (up to 35 m) and for the longer distances the prismatic option is of better accuracy than reflectorless option [10] for used total station. Also, this research showed that increasing inclining angle leads to increase of distance measurement error. Research for the accuracy of distances measured by reflectorless technology in the range of 50 m resulted by conclusion that correct measurement fluctuates between 20% and 85%, which means that reflectorless technology needs improvement [11]. The long-range reflectorless distance (up to 1000 m) measurements show that the accuracy is dependent on the incidence angle and that the size of target shall increase with distance [12]. Also the specified accuracy for long mode decreases at the value of 10 mm + 10 ppm. In order to investigate the performance of reflectorless total stations the researchers [13] carefully established geodetic test line. Common characteristic for all quoted research is the carefully controlled conditions for reflectorless measurements of distances. In practice however the surveyors could not control the conditions and the results of distance measurements obtained by reflectorless technology are rarely possible to be checked. This problem indicates that obtained result of distance measurement should be reliable and obtained in efficient manner which means that measurement in one position of total station's telescope should be accurate in the range of declared accuracy for used total station. Also in practice the type of surface, distance and incidence angle could not be chosen by the researchers' free will which means that the measurements should be performed with the limits defined by site.

In this paper the concept of measurement reliability is used in the sense of the trust which we could have in the obtained measurements i.e. should the reflectorless measurements be trusted without repetition.

The experiment for this research was designed to check the real conditions on the site and encompassed distance measurements on two different kinds of surfaces and with two different kinds of sighting. The surfaces are defined as regular and irregular while the sighting was completely manual and automated. Regular surface is defined as a surface with known roughness and irregular surface is defined as surface with unknown roughness. Regular surface is obtained by targets printed on the paper (A4 dimension) while for the irregular surface the cross written on the concrete surface was utilized. The manual sighting means that complete measurements were provided by sighting with manual corrections while automated sighting means that only in first position of telescope sighting was provided manually but in further measurements the results were only recorded in the position reached by total stations. All measurements were provided in two sets of angles.

The obtained results of measured distances were analysed in two ways: internal analysis which encompassed differences obtained for the same distance measured in different positions of telescope in two sets of measurements and external analysis which encompassed differences between obtained results of distances and their "true" values. "True" values of distances were obtained from adjusted coordinates in geodetic network.

The main aim of research was to test the accordance of distances as follows (both for types of sighting and types of surfaces):
- Equality of distances obtained by adjustment of manual and automated sighting (two sets of data for the same network of points);
- Equality of distances obtained in two sets of measurements (equality of their averages in two positions of telescope);
- Equality of distances obtained by manual and automated sighting and
- Equality of distances obtained by reflectorless measurements and their "true" values obtained from adjustment.

The equality of distances was determined by utilization of common statistical methods [14].

2 MATERIALS AND METHODS

The data of this experiment were obtained through measurement of directions, zenith angles and distances in two sets of measurements in the network designed for testing quality of reflectorless distance measurements. Three massive concrete pillars were adopted for measurements with prisms and six free stations were utilized for measurements on targets with reflectorless technology. The targets were aligned in almost straight line on the distance of approximately 200 m.

On each free station the two sets of measurements were provided: measurements with manual sighting and the measurements with automated sighting. Each of these measurements (with manual and automated sighting) was provided in two sets of measurements. The analysis is provided in four possible combinations as given by Fig. 1.

Surface		Type of Sighting	
		Manual	Automated
	Regular	Regular Surface and Manual Sighting	Regular Surface and Automated Sighting
	Irregular	Irregular Surface and Manual Sighting	Irregular Surface and Automated Sighting

Figure 1 Combinations of data analysis

The "true" values of distances were obtained through adjustment by using least square model:

$$l = Ax \qquad (1)$$

$$[pvv] = \min \qquad (2)$$

$$[x^T x] = \min \qquad (3)$$

The "true" values of distances measured by reflectorless mode were determined by utilization of distances measured on prisms mounted on pillars and horizontal directions.

The differences were obtained by the formulae:

$$\Delta_i = D_{ij}^T - D_{ij} \qquad (4)$$

$$\Delta_i^T = D_{ij}^T - \overline{D}_{ij} \qquad (5)$$

where: Δ_i - difference between "true" value of distance and results obtained by reflectorless measurement for each value in two sets; Δ_i^T - difference between "true" value of distance and average reflectorless measurement for all values in two sets; D_{ij}^T - "true" value of distance determined from adjusted coordinates; D_{ij} - each value of distance measured by reflectorless and $\overline{D}_{ij}$ – average value of measured distance by using reflectorless mode.

The statistical tests were provided by utilization of Student's distribution:

$$t = \frac{d}{m_d} \sim t_{f,\alpha} \qquad (6)$$

where: t - Student's statistics; d - difference between tested distances; m_d - mean squared error of difference d and $t_{f,\alpha}$ - quantile of Student's distribution for degree of freedom f and level of significance α (in this analysis is adopted $\alpha = 0.005$).

The mean squared error for distances obtained from adjusted coordinates is calculated by the following formula:

$$m_{D_{ij}^T} = m_0 \sqrt{g^T \boldsymbol{Q_x} \boldsymbol{g}} \qquad (7)$$

where: $m_{D_{ij}^T}$ - means squared error of distance

determined by adjustment; m_0 - mean squared error of adjustment; $\mathbf{g}$ - vector of factors and $\mathbf{Q_x}$ - cofactor matrix.
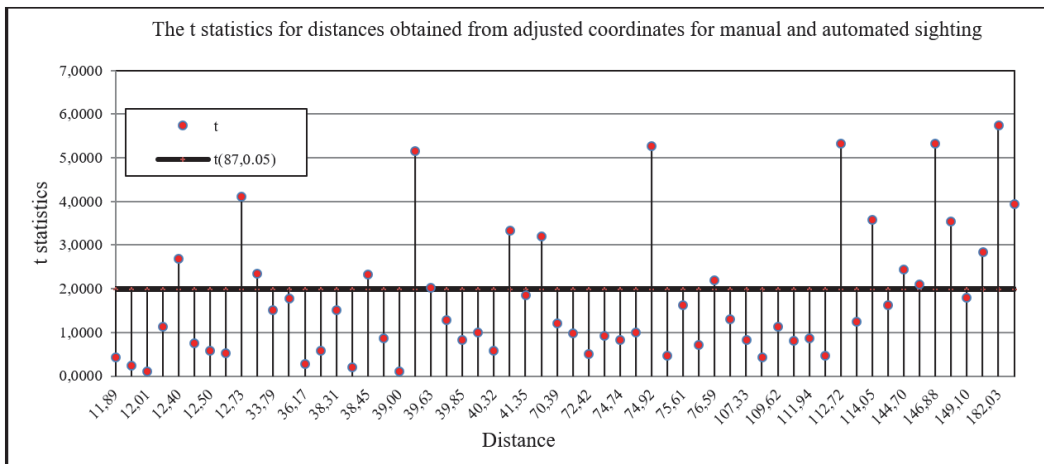

Figure 2 t statistics for distances obtained from adjusted coordinates for manual and automated sighting
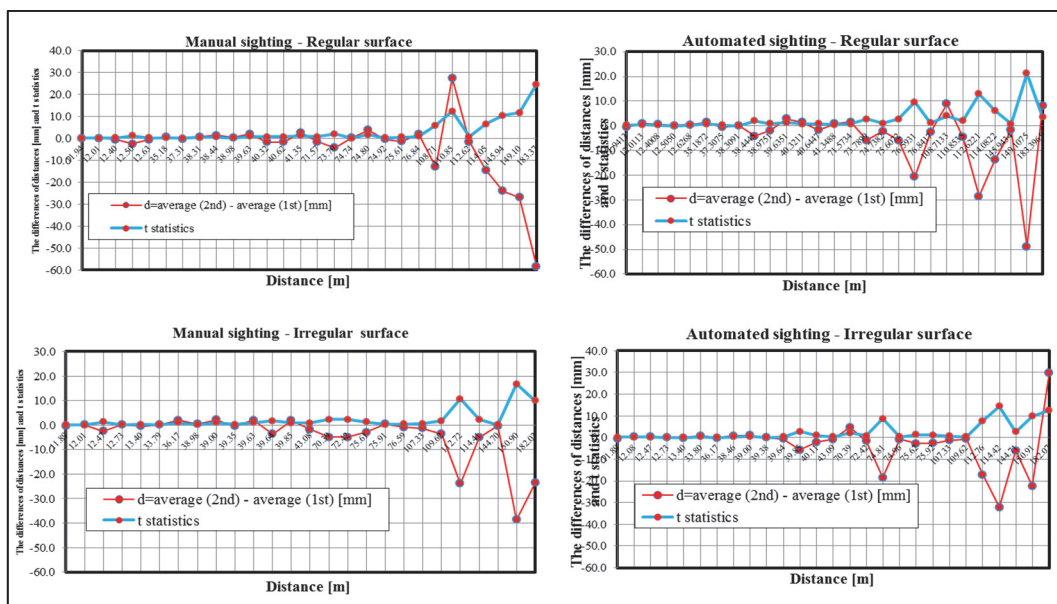

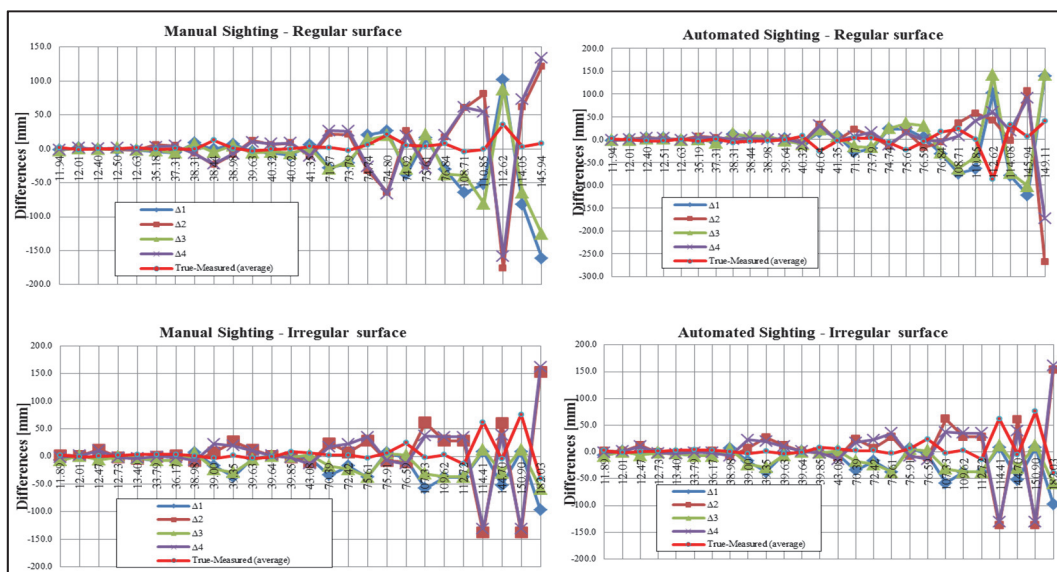**Figure 3** The differences of distances measured by reflectorless and their "true" values

Figure 4 The differences of distances measured by reflectorless and their "true" values

3 RESULTS AND DISSCUSSION

The results are shown in the following order:
- Equality of adjusted distances without reflectorless measurements from results obtained by manual and automated sighting (Fig. 2). The obtained results showed that automated sighting produced the differences in 33% cases (19 adopted alternative hypotheses vs. 39 adopted hypotheses);
- Equality of reflectorless measured distances between averages in the 2nd and 1st set (Fig. 3). The obtained results showed that acceptance of null hypothesis varies from 63% to 75% (acceptance of alternative hypothesis varies from 25% to 37%);
- Equality of differences between distances measured by reflectorless and their "true" values as well as differences between themselves (Fig. 4). The obtained results showed that acceptance of null hypothesis varies from 58% to 78% (acceptance of alternative hypothesis varies from 22% to 42%).

The acceptance of null hypotheses (equality of measured distances by reflectorless technology between averages in 1st and 2nd set) for manual and automated sighting (both for regular and irregular surface) is shown in Tab. 1, while the acceptance of null hypotheses (equality of measured distances by reflectorless technology between average in two sets and their "true" value) for manual and automated sighting (both for regular and irregular surface) is shown in Tab. 2. For the purpose of this analysis, $\sigma_d = 2 + 2$ ppm is adopted (which is in accordance with the used total station in this research) for the measured distance with reflectorless technology and $m_{D_{ij}^T}$ was obtained from

adjustment.

Table 1 The acceptance of null hypotheses for differences of average distances between two sets

		Sighting	
		Manual	Automated
Surface	Regular	75%	63%
	Irregular	73%	70%

Table 2 The acceptance of null hypotheses for differences of average distances and their "true" values

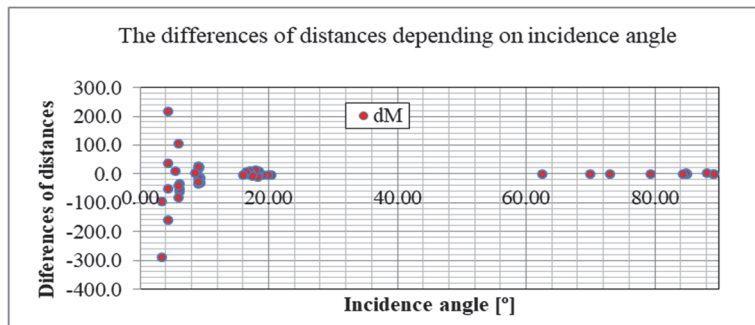|		Sighting	
		Manual	Automated
Surface	Regular	78%	66%
	Irregular	73%	58%

According to obtained results it is obvious that automated sighting resulted by lower level of null hypothesis acceptance than manual sighting both for regular and irregular surfaces. Also the automated sighting resulted by lower level of null hypothesis acceptance than manual sighting both for differences of distance averages between two sets of reflectorless measurements and for differences between overall average of reflectorless measured distances and their true values. The analysis showed that the differences increase with the increasing of distances.

The relation between distance and incidence angle β and distance is given by the following formula:

$$\beta = \arcsin \frac{h}{D} \qquad (8)$$

where: h - distance from free station to the line of targets and D - horizontal distance from free station to target.

The dependence of differences between measured distances by reflectorless technology and their "true" values are shown in Fig. 5 for the case of manual sighting and in Fig. 6 for the case of automated sighting.

Figure 5 The differences of average distances and their "true" values for the case of manual sighting
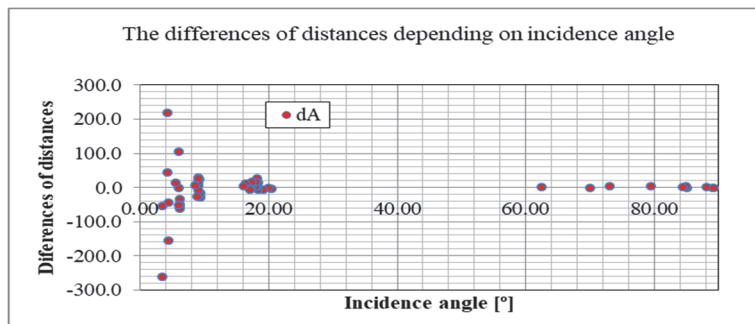
Figure 6 The differences of average distances and their "true" values for the case of automated sighting

Considering the dependency of differences between distances measured by reflectorless technology and their

"true" values it is obvious that for incidence angles smaller than 20º they vary significantly and in unpredictable manner.

4 CONCLUSION

According to obtained results and for conditions (surfaces, instrument and type of sighting) utilized in current experiment it is possible to conclude that for the utilization of reflectorless technology it is necessary to provide measurements at least in two positions of telescope especially if incidence angle is smaller than 20º. The differences could vary in unpredictable manner and could take the values greater than expected, regardless of regularity of surface and type of sighting. Only in cases when the distances are small it is possible to obtain acceptable results even in case of incidence angles smaller than 20º but also if they were measured in, at least, two sets of angles. The reliability of repeated measurement of distances by reflectorless technology increases with number of measurements but must be used very carefully in real conditions with considering type of surface, distance and incidence angles.

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