Some aspects of spatial data acquisition using total stations

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Abstract
This article presents some aspects of measurement accuracy using total stations, regarding the correction of the measured acquired values, of mathematical corrections at the level of sensors involved and not least access to specific correction values.

Keywords
Spatial data acquisition, total stations, instrumental corrections

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1. Introduction

The measuring methods of surveyors were changed, after 1960, when were launched the first electronic distance measuring devices. The expanted geodetic networks gradually renounced at the exclusive triangulation networks. In their place were developed combined networks by directions and distances or trilateration networks. In determining the points on small areas, cadastre and topography, has moved from optical measurement to measure distances electronically. In determining the points on small areas, in cadastre and topography, it passed from optical measurement to electronically measuring of distances.
Combining instruments for measuring angles and distances was a logical consequence. At first, to determine angles and distances were using separate tools. For high accuracy requirements, common geometric reference was provided through forced centering of instruments.
In 1968 the Zeiss company introduced Rec Elta 14 instrument, which is the first electronic tachymeter with data record. In 1990, when the company Geotronics introduced System 4000, it starts the „motorized tachymeters age”. At the same time appear on the market GPS systems for determining the 3D points, especially as an alternative to tacheometric measurement systems. Some manufacturers have already announced the end of land measuring technique. However electronic tachymeters were consistently developed further.
Next the tachymeter term is used as a generic term for all systems, in which are achieved electronic combined measurement of directions and distances. In the past several names were invented, which always contain a reference to the stage of development at the time [1]. Through autoreductor tachymeter term, computer assisted tachymeter or computerized tachymeter, for example, in 1980, advertised the functionality of automatic calculation of horizontal distance. Today this is something natural and is not specifically mentioned. Currently, manufacturers are talking about computerized tachymeters and refer to instruments that integrate complex interactive softwares with operating systems that are specific to computers (Windows CE) and allow the specific operation of a computer, such as the operation with the digital maps, with images, with computer

aided graphic editing and even application development environment, where users can create their own routines for improving productivity.

Electronic tachymeters, generally with a range of up to 3000 m, can be classified by a first criterion, depending on measurement accuracy directions, as follows:

- Instruments with a standard deviation < 5 ^{cc};
- Instruments with a standard deviation of 5^{cc} to 20 ^{cc};
- Instruments with a standard deviation > 20 ^{cc}.

where the distance is measured once with accuracy of ± (5 mm + 5 · 10^{-6}D).

This classification takes into account only the measurement accuracy directions, distance measurement accuracy is considered constant. In addition, equipment features and functionality that tachymeter gives to the users are not considered.

1. The accuracy of measuring angles and distances with electronic tachymeters.

An uncertainty in the horizontal direction is equivalent to a deviation of sight perpendicular to the reference point (cross deviation).

It grows linearly with distance. The same is true for vertical angles. A distance measurement uncertainty can be interpreted geometrically as a deviation from the target direction (longitudinal deviation). The data accuracy of the distance measurements are composed of a constant part and one proportional to the distance. Therefore, the uncertainty increases with increasing distance; but it does not increase with distance. In figure 1 are represented the relations for the direction and distance accuracies of tachymeters for a distance of 500 m.

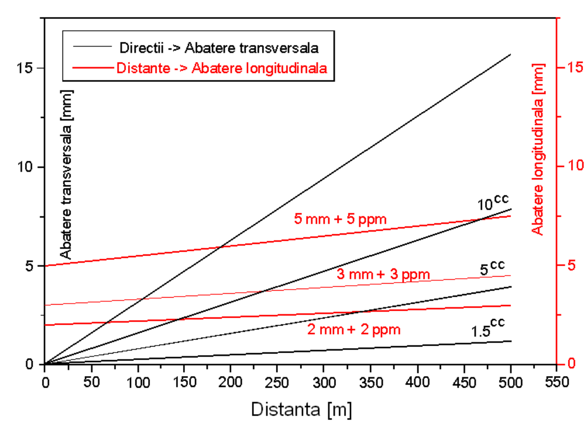

Fig. 1 Measuring accuracy of directions and distances

At a polar measurement of points it is desirable the situation of an isotropic, that is, the longitudinal and transverse deviations should be approximately equal. With an instrument, this may be true, strictly taken, only for one distance (Figure 2). In case of tridimensional measurements (position and height), height component should be considered accordingly.

Precision values of measurements of angles and distances are shown in Figure 2 in the form of ellipses of errors. For short distances (1), observed horizontal directions (ie vertical angles) are superior distances in terms of accuracy. In a medium range (2), usually between 200 and 600 m, isotropic error situation occurs. If landmarks are further away (3), the inaccuracies of measurement angles are greater than those of measurement of distances.

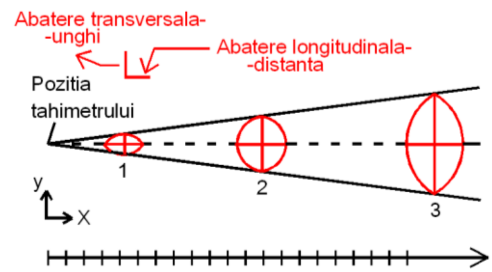

Fig. 2 Directions and distance measurement accuracy

Precision values of measurements of angles and distances are shown in Figure 2 in the form of ellipses of errors. For short distances (1), observed horizontal directions (ie vertical angles) are superior distances in terms of accuracy. In a medium range (2), usually between 200 and 600 m, isotropic error situation occurs. If landmarks are further away (3), the inaccuracies of measurement angles are greater than those of measurement of distances.

In terms of construction, angle measurement accuracy has been improved by manufacturers over the last decade. In principle this is also true for electronic measuring distances [3].

Instead it has been simplified and accelerated obtaining the measurement values. Today electronic tachymeters are multisensor systems with integrated computing units. The calculations, which before were only possible in the office, today can be performed on site and interactively [2].

In fact, all companies offer different series of devices to meet a wide spectrum of customers.

2. Correction of measured values at electronic tachymeters

Original and corrected observations

In case of electronic tachymeters there are no original measured values as well as the optical theodolites, because before values can be accessed by the user (via display or memory), they are often corrected by calculation. Corrections take into account different factors:

Sensor calibration

That means, in general, the metrologycal behavior of the sensor during measurement. Calculated compensation is carried out by means of a characteristic curve obtained from a polynomial or a table of values. In general, sensor variations are found in the law of propagation counted. Often are using simplified calculation modes, such as when in a linear model corrects only a standard deviation of zero.

Temperature Behavior

The temperature is recorded and taken into account in the calculations.

Geometric deviations of the instrument

In addition to the conditions on the axis (major axis tilt error in the direction of the axis of sight and tilting axis of the telescope), for precision measurements are taken into account in computing also eccentricities or adjustments of individual components.

Current oblique position of the vertical axis

An oblique position of the vertical axis in space falsify repeatedly, horizontal and vertical angle measurements. Longitudinal component l acting in the direction of sight, affects the correct measurement of vertical angle; transverse component q acting in the direction of the telescope axis, affects the correct measurement of horizontal directions. Recording the actual inclination of the main axis through the measurement technique, these influences can be canceled by calculation.

Oblique position of the vertical axis also causes an error of eccentricity, which is generally negligible. It should be considered only in case of very short distances, which occur for example in precision measurements in an industrial environment.

The distortion of horizontal angle is caused by an eccentricity h between the point on the ground obtained from a centering by coercion B and the intersection point K between the axis of sight and the tilt axis of the telescope (Fig. 3).

Reported to zero direction of the horizontal circle, instead of seking horizontal direction a1 will be observed a'1.

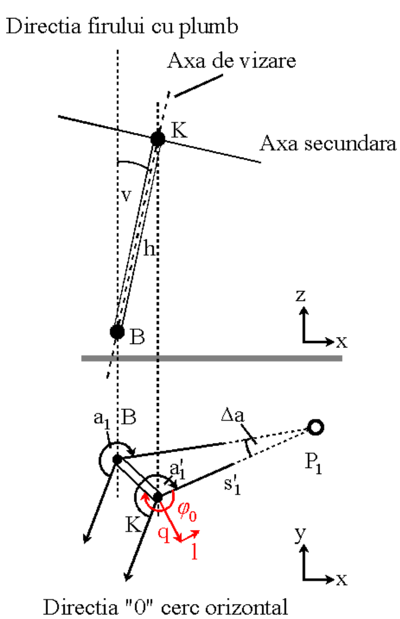

Fig. 3 Eccentricity due to oblique position of the vertical axis

φ_0 = tilt direction of the vertical axis to the direction of the objective;

l = longitudinal component towards the objective;

q = transverse component in secondary axis direction of tachymeter, transverse to the the objective direction;

v = vertical axis inclination;

e = horizontal eccentricity;

Δa = requested correction;

ρ = conversion factor = 200G/π

Correction Δa is calculated as follows:

$$\left.\begin{aligned} \varphi_0 &= \arctan\left(\frac{l}{q}\right) \\ \sin(\Delta a) &= \frac{e}{s_1'}\sin(\varphi_0) \\ \Delta a &= \frac{h \cdot \sin v}{s_1'} \cdot \rho \cdot \sin(\varphi_0) \end{aligned}\right\} \quad (1)$$

In case of sighting points at large distances eccentricity does not occur. Correction Δa becomes significant only on short distances and if there is a clear oblique position at the working edge of compensator (see Table 1).

Table 1 Eccentricity of Hz direction due to the tilt of the vertical axis

Instrument height h			1,50 m
Horizontal angle φ_0			80^G
Tilt of vertical axis v			$0{,}05^G$
Distance s'1	5 m	10 m	20 m
Δa [cc]	150^{cc}	75^{cc}	37^{cc}

After triggering a measurement, in the first instance, are selected sensors involved. This is followed by a mathematical correction at the sensor level, which are not accessible to the user.

A higher level consists of "geodetic measured values", where the operator can select or change some corrections, which are then applied to the measured values. The possibilities with the most important influence are shown in Table 2.

Table 2 Geodetic corrections for direct measurements

Measurements	Correction for ...
Horizontal directions Hz	Error of sighting axis and tilt axis of the telescope
	Tilting vertical axis
	Horizontal reference direction
Vertical angle V	Index error
	Tilting vertical axis
Sloping distance s'	Additional corrections
	Propagation speed
	Scale factor (ppm)

A concrete example of generating angles for a precision electronic tachymeter is shown below, using the following symbols:

XRaw = "raw" value of the sensor without correction;

k_{cx} = sensor calibration correction;

k_{tX} = temperature correction of the sensor;

k_{JX} = correction adjustment of the sensor

kn_{PX} = correction due to the unparallelism between the axis of sight and the longitudinal tilt axis respectively between the minor axis and the transverse tilt axis

c = collimation error

i = secondary axis tilt error

The following values appear on the display:

Longitudinal inclination: $L = L_{Raw} + k_{cL} + k_{tL} + k_{JL} + k_{nPL}$

Transverse tilt: $Q = Q_{Raw} + k_{cQ} + k_{tQ} + k_{JQ} + k_{nPQ}$
Vertical angle: $V = V_{Raw} + k_{cV} + k_{tV} + k_{JV} + k_{Vi} - L$

$$k_{Hz} = \frac{c}{\sin(V)} + \frac{i+Q}{\tan(V)}$$

Horizontal direction: $Hz = H_{Raw} + k_{cH} + k_{tH} + k_{JH} + k_{Hz} - Hz_0$

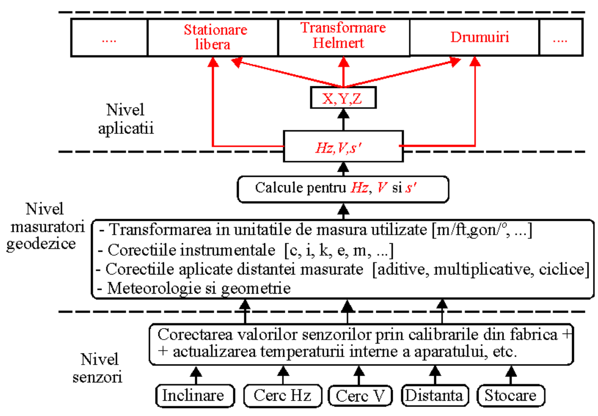

Fig. 4 Different levels on correcting the measured values of electronic tahymeters

Inclined distance s' is analog calculated from a raw measured value, which is modified by applying internal corrections (additional and cyclical corrections) and external corrections (eg. ppm value correction due to weather and constant prism correction). The measured values, before being displayed, are converted into selected unit by the user (for distance / angle).

From the directly measured values, the electronic tachymetric software calculates derived quantities such as the horizontal distance, the difference in level between the center-of-sight of the total station and the target point, cartesian or polar coordinates.

3. Access to the correction values

The user wants that the tachymeter can be used in a simple and intuitive way, without having to constantly consult the user manual. At the same time, the user expects at a high security data, so low battery or pressing a wrong key does not lead to data loss.

From the point of view of producers, they take into account, given the global competition, not just languages, mentalities and different working modes, but also different levels of training, from semi-skilled operators without the geodetic training to technicians, surveyors, respectively geodetic engineers.

In order to ensure a simple and non-vulnerable operation, the user can not view or modify algorithms and corrections to the sensors level. Even geodetic corrections to be taken into account, can not always be accessed. Each instrument allows the introduction of a single additional correction for distance measurement or a new bearing for setting the horizontal circle.

For corrections of axes are different situations. While some tools allow the direct introduction of collimation error, the others a new introduced value can be possible only indirectly, by taking measurements in both faces. When checking instruments, it can be seen that not all influences are taken into account properly. In concrete terms it already appeared programming errors (bugs) or approximate solutions were used instead of exact algorithms, when for example the influence of vertical angle is not taken into account in determining the collimation error..

Secondary axis situation is one that would require improvements: many instruments, especially the middle class precision, although the telescope overthrow axis error can be read, it can not be changed. There are even instruments that run a correction, but the values themselves can neither be read nor modified.

If corrections can be accessed only partially or not at all, then often they are only mentioned in the instruction manual or are not documented at all, so the user does not know to what extent these instrumental corrections influence actually the measurements

User advantage lies in easy handling of the measuring equipment. Instead, he can not make an accurate view of actual measurement quality or can not use the full potential of the instrument precision. From a user perspective it is hoped that producers of future geodetic instruments allow at least correction readings that are relevant from geodetic point of view. The ideal solution would be an output file, in the idea of quality assurance and prosecution of measured values. In addition, fundamental algorithms should be documented accurately.

4. Conclusion

Today, many users work "directly" with coordinates and are not interested at all of the elements of direct measurement. Such a process can be an economic one for a series of measurements, but in the case of precision measurements is recommended that direct measurements to be assessed or treated in a professional manner.

Astăzi, sistemele GPS şi tahimetrele electronice sunt văzute mai puţin ca două grupe de produse concurente, ci mai mult ca două tehnologii de măsurare diferite, care se completează în mod util prin intermediul punctelor forte şi al punctelor slabe specifice.

Today, GPS systems and electronic tahymeters are seen less as two groups of competing products, but rather as two different measurement technologies that complement effectively through specific strengths and weaknesses points.

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