Determination of control network accuracy and coordinates of control points in facade surveying

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Abstract. The paper presents ways to determine the positions of control points with electronic total stations of varying accuracy from 1 to 5 seconds with and without reflectors at the sighting points, depending on the degree of vertical and horizontal positioning to the control points located at a distance of 50 m. It provides accuracy parameters of points in a high-order control network, containing root-mean-square positioning errors, the resultant error, the sizes and orientations of the semiaxes of the error ellipses and root-mean-square positioning error distributions. The paper considers an algorithm for performing facade surveying.

1. Introduction

The authors were concerned with geodetic façade surveying for a block of flats with community facilities on the ground floor and an underground parking space in order to get a three-dimensional model of the building through tacheometric surveying, resulting in geometric façade characteristics. To provide high-quality surveying, geopositioning accuracy of the control points was determined with electronic total stations of varying accuracy from 1 to 5 seconds, depending on the degree of vertical and horizontal positioning to the control points located at a distance of 50 m. In addition, the authors determined the accuracy parameters of the points in a control network, root-mean-square positioning errors, the resultant error, the sizes and orientations of the semiaxes of the error ellipses and root-mean-square errors of points. The measurements were processed using the Credo_Dat software. A 3D façade model was drawn in an AutoCAD software.

2. Problem Statement

Facade surveying is used to solve a number of tasks, including determining:

- positioning of all façade elements (cornices, window and door openings, balconies, protruding plinths, awnings, various decorative elements, etc.);
- stress-strain state of objects;
- digital model for restoration;
- scope for hinged ventilated design, etc.

Each of the above tasks requires a different accuracy in obtaining the positions of the control points. The scientific and technical literature widely covers the methods for performing façade surveying [3–11]. However, there are much fewer publications that deal with control network precision for façade surveying [1, 2, 12], contouring accuracy and increase in coordinates of the control points. Therefore, it is urgent to study this issue.
3. **Research Questions**
The paper explores control network precision and the position accuracy of the control points during façade surveying.

4. **Purpose of the Study**
The paper aims to determine the characteristics for geodetic control network precision and increase in coordinates with total stations of varying accuracy.

5. **Research Methods**
The methods used involved observation, system analysis, comparative analysis, modeling.

6. **Findings**
The facades were surveyed through stadia tacheometry. Stadia tacheometry involves a set of activities aimed at geopositioning of control points in a unified coordinate system (Figure 2), i.e. getting a 3D model of an object. These activities are most optimal to perform with an electronic total station that measures horizontal $\alpha$, vertical $\nu$ angles and a slope distance $S$, from the station to a point (polar coordinate system).

![Figure 1. Scheme for determining positions ($x$, $y$, $z$) with a total station](image)

Working equations for converting polar coordinates to Cartesian coordinates are:

$$
x = x_0 + \Delta x; y = y_0 + \Delta y; z = z_0 + \Delta z; \quad h = s \cdot \sin \nu; \quad \Delta x = s \cdot \cos \nu \cdot \cos \alpha; \quad \Delta y = s \cdot \cos \nu \cdot \sin \alpha.
$$

These functions, we switched over to their mean square errors

$$
m_h^2 = m_\nu^2 \cdot \sin^2 \nu + s^2 \cdot \cos^2 \nu \cdot \frac{m_\nu^2}{\rho^2};
$$

where $x, y, z$ are the positions of a point to be determined; $x_0, y_0, z_0$ are the datum positions; $\nu, \alpha$ are vertical and horizontal positioning; $s$ is a slope distance; $x, \Delta y, \Delta z$ are coordinate increments.
\[ m_{\Delta x}^2 = m_s^2 \cdot \cos^2 \nu \cdot \cos^2 \alpha + s^2 \cdot \sin^2 \nu \cdot \cos^2 \alpha \cdot \frac{m_v^2}{\rho^2} + s^2 \cdot \cos^2 \nu \cdot \sin^2 \alpha \cdot \frac{m_\alpha^2}{\rho^2}; \quad (2) \]

\[ m_{\Delta y}^2 = m_s^2 \cdot \cos^2 \nu \cdot \sin^2 \alpha + s^2 \cdot \sin^2 \nu \cdot \sin^2 \alpha \cdot \frac{m_v^2}{\rho^2} + s^2 \cdot \cos^2 \nu \cdot \cos^2 \alpha \cdot \frac{m_\alpha^2}{\rho^2}; \]

where \( m^2 \) is \( h, \Delta x, \Delta y \) mean square error.

Using the above formulas, a graph was built for the dependence of positioning uncertainty on the accuracy and degree of positioning. (horizontal and vertical angles varied from 0° to 180°, the distance was taken 50 m). The formulas (3) indicate that the equations for \( m_h \) and \( m_{\Delta y} \) are identical at a vertical angle equal to 0° (they differ solely in the form of a taken angle), then a joint graph is built for them, shown in Fig. 3. Based on the formulas (3), mean square error \( m_{\Delta y} \) is inversely proportional to \( m_{\Delta x} \). To ensure façade control in a unified conditional coordinate system and heights around the building, the control points were delimitated and compiled in a control network. Figure 4 shows a diagram of the reference position of the total station (ST), datum points (T) and control points (pegs) relative to the facades. The geometric parameters of the facades were controlled from 6 stations.

![Figure 2. Accuracy calculations for \( m_h \) and \( m_{\Delta y} \).](image-url)
The control network is formed by linear-angular constructions.

Table 1 and Fig. 5 shows the accuracy parameters of the points in the control network, which contain:
- root-mean-square positioning error distributions along the X and Y axes ($M_x$, $M_y$) and the resultant error $M = \sqrt{(M_x^2 + M_y^2)}$);
- sizes and orientations of the semiaxes of the error ellipses ($a$, $b$, $\alpha$);
- positioning error distributions $M_h$. 

**Figure 3.** Schematic for positioning of the station vs the control points

**Figure 4.** Positioning error distributions
Façade surveying was supported by the following technique. An electronic total station on a tripod was positioned off a surveyed façade at a distance approximately equal to the height of the building. A station coordinate system was aligned parallel to a line passing through the corners of top windows of the facade being surveyed. In a single coordinate system, all corners of windows, walls and the visible contours of the building were tied. The measurements were automatically recorded by an electronic total station into a selected measurement file. After the measurements were taken, the file was transmitted to a computer. After that, the file was imported into the Credo_Dat program designed to ensure processing of field engineering and geodetic measurements. The program converted the polar coordinates into Cartesian coordinates and the obtained 3D coordinates of points were exported to an AutoCAD format (*.dxf). The resulting file then was opened with AutoCAD, where the facade
geometry was properly drawn. Eventually, façade surveying resulted in a 3D model of the building, shown in Fig. 5.

![3D model of the building](image)

**Figure 5.** 3D model of the building

The 3D model of the facades is simulated in a unified conditional coordinate and height system. Each façade is individually made in its own conditional coordinate system, the $X$ axis is directed (outward) from the building, the $Y$ axis is directed (to the right) along the wall, the $Z$ axis is directed vertically (upward). The reference zero is shown in all figures.

The results were transferred to the customer, both in paper and digital form (in the AutoCAD program). One drawing is presented for each façade. They highlight windows, avant-corps, building contours (arris and roof) and the plane of walls (all deviations from the principal plane in m).

The rule of signs. Deviations to increase the size of the building have a (−) sign, to reduce the size (inside the building) have a (+) sign.

7. Conclusions

Determinations of the positions of the control points with electronic total stations of varying accuracy from 1 to 5 seconds with and without reflectors at the sighting points, depending on the degree of vertical and horizontal positioning to the control points located at a distance of 50 m show that maximum RMS value is reached with a 5 second total station with a distance measurement accuracy of 3 mm at a horizontal and vertical angle close to 90 degrees, minimum value – at vertical and horizontal angles close to 0 and 180 degrees. For a 1 second total station, RMS value for determining coordinates at any angles does not exceed 1 mm.

The maximum positioning error is 3mm for survey point S1, the minimum is 1mm for several points.
The maximum total positioning errors of points is determined at point ST1 0.024 m (24 mm), respectively, and the sum of the major and minor semi-axes of the error ellipse at this point is maximum – 0.024+0.03=0.027 m (27 mm).

The minimum total positioning errors of points at ST1 is 24 mm, respectively, and the sum of the major and minor semi-axes of the error ellipse at this point is minimal – 0.004+0.002=0.006 m (6 mm).

Based on the findings, the façade surveying of a block of flats with community facilities on the ground floor and an underground parking space was performed with sufficient accuracy and can be used for further development of project documentation.

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