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DETERMINATION OF GEODETIC CONTROL NETWORK POINTS USING GPS TECHNOLOGY FOR THE PURPOSE OF MONITORING POWER LINES IN DIFFICULT TERRAIN CONDITIONS

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Summary

The present work discusses the issue of determining geodetic control network in order to monitor the condition of power lines. The problem was presented using the example of the physical survey of an actual infrastructure – a high voltage power line. Difficult terrain conditions constituted a significant factor for determining an appropriate measurement method. The measurement itself was conducted using two methods, independently of one another: the classical traverse method, and the RTK (Real Time Kinematic) GPS method. The following criteria were assumed for the purpose of the comparison: measurement effectiveness and the accuracy of the calculation result. Basic monitoring procedures of power lines were also presented, implemented based on the measurement network established beforehand.

Keywords

monitoring of power lines • control survey network • RTK GPS method

1. Introduction

In establishing a measurement matrix, it is increasingly common in the surveying practice to apply satellite technologies, which do not require the surveyor to locate the particular geodetic structures in the field [Góral et al. 2008, Lamparski 2003, Leick 2004]. The condition for the accuracy of measurement in this case is the availability of an appropriate number of satellites – and that condition is not always possible to meet. Satellite signals can be disrupted: by vegetation, buildings, landforms, etc. Therefore satellite technology cannot entirely replace the classical (ground) measurement techniques.

Furthermore, the overall development of technology in recent decades contributed to the improvement of measurement instruments, used in classical methods. Contemporary digital tachymeters facilitate the creation of wholly automated measurement and calculation technology: from reflector-less survey – via automatic registration of results – wireless transmission of data to a computer – to numerical elaboration (calibrating the observation and calculating the coordinates). Survey stations (Total Stations) are moreover equipped with software, which conducts the calculations directly on the spot, facilitating the delivery of complete coordinates for the determined control points.

The aim of the present work is to conduct a comparative analysis of the GPS technology versus the classical traverse method for establishing a measurement network in unfavourable terrain conditions. Two criteria were assumed for the purpose of the comparison: the accuracy of the calculation result, and measurement effectiveness. The characteristic features of the measured object consisted in varied terrain and prevalence of forest. The determined control network facilitated geodesic control measurements of high voltage power lines 110 kV [Jawor 2009]. In order to verify the accuracy of the measurement effected in the GPS technology, closed traverse was designed using the same control points. The objective was to demonstrate which of the methods is most suitable in difficult terrain conditions.

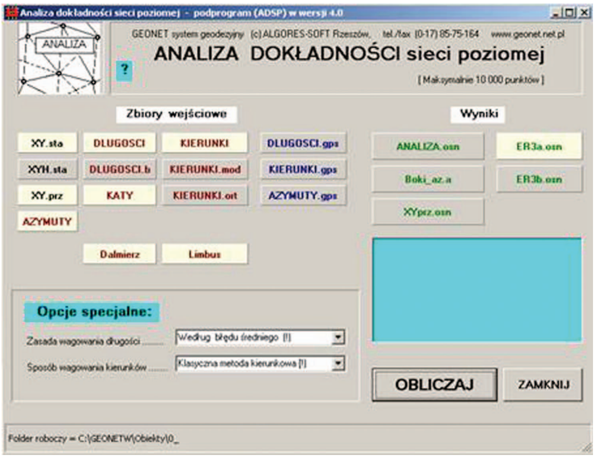
2. Principles of designing measurement networks

The first stage of establishing a measurement network is to develop a design thereof, after which follows the stabilisation of points, measurement, calculation, and elaboration of measurement results, completion of the report, and delivering the latter to the client. The purpose of designing and establishing geodesic networks in a given area is to ensure the required coverage of the land with a network of the appropriate class of accuracy, and to guarantee a determinate density of control points. The design must be preceded with a reconnaissance of the existing range of the newly designed network, terrain conditions, the general concept of the State network, as well as current and predicted future needs in terms of equipping the given area with a geodesic network. One must also select the most appropriate and useful structure of the network and the measurement technique, which facilitates as accurate designations as it is feasible, with the lowest possible costs of the project's implementation [Regulation… 2011, GUGiK 2002].

One of the stages of a properly conducted network designing process should consist in a prior accuracy analysis [Kadaj 2006]. Results of the said analysis provide foundations for the assessment of the network design, its correctness, and possible modifications to the structure or correction to the accuracy of measurement, assumed a priori. This task can be performed, for instance by using one of the calculation modules of the Geonet software [Kadaj 2006]. After entering the command in the main dialogue window: Geo-spec/ Initial analysis of horizontal network, a new window opens for the studied network (Figure 1).

The software does not require entering real observation measures; one only needs to declare observation plans, and approximate coordinates. This analysis makes it possible to determine the target model of network accuracy, which the results of the adjustment should aim towards. Initial accuracy analysis programme utilises the same data sets, identical in name and structure, as the rigorous adjustment programme. Declared observation measures can be expressed with any nonnegative number, for instance: instead of length measures, angles, directions and azimuths, zero can be entered.

Record structures should be identical as in the case of data collated for network adjustment. If the following conditions are met, then the network we prepare for adjustment (or one that is already adjusted) can be subjected to the initial accuracy analysis in the same data folder, based on the same data.



Zasada wagowania długości .... Według błędu średniego [!]

Sposób wagowania kierunków .... Klasyczna metoda kierunkowa [!]

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Fig. 1. Dialogue window of the Geonet software: "Initial analysis of horizontal network"

When designing area measurement using GPS technology, we should consider not only the target accuracy of point coordinates, but also a manner of relating to the frame of reference, measurement method, type of data transmission, types of receivers, and the method of data preparation from satellite observations. At present, a commonly used solution is linking the measurement data to the reference points of the ASG-EUPOS system [Bosy et al. 2008]. General determinants for using calculation services of the aforementioned system are shown in Table 1.

Table 1. Accuracy of GPS measurement in the ASG-EUPOS system

Type	Name	Method of measurement	Data transmission	Assumed accuracy	Minimum hardware requirements
Real time services	NAWGEO	kinematic (RTK)	Internet, GSM (GPRS)	Up to 0.03 m (horizontal) Up to 0.05 m (vertical)	L1/L2 RTK receiver, communication module
	KODGIS	kinematic (DGPS)		Up to 0.25 m	L1 DGPS receiver, communication module
	NAWGIS			Up to 3 m	
Post-processing services	POZGEO	static, rapid-static	Internet	Depending on measurement conditions (0.01–0.10 m)	L1 receiver
	POZGEO D	Static, kinematic			

3. Geodesic control of power lines

Control measurements of power lines, as in the case of any other infrastructure object, are aimed at determining any discrepancies between the setting out survey of the infrastructure, and the as-built survey. The results should be shown in working drafts and survey logs kept during the measurement process. All data is then collated in the acceptance protocol and handover inspection report. In the case of discrepancies with the state of construction, all differences should be approved by the designer, by the construction inspector, and by the user of the infrastructure. The list of the differences and their approval is entered in the handover inspection protocol. Resultant modifications should also be shown in the project documentation, with a note of control survey measurements conducted, and confirming that the users of infrastructure have been duly informed.

When surveying power lines, depending on the client's requirements, the following elements are taken into consideration [Migas 2000]:

- placement of the transmission towers in land lots (parcels of record),
- settings of electrical power appliances,
- length of the section, spans, insulation,
- height of the transmission towers,
- sag of live wires and arrester wires,
- any crossover with other power cables or telecommunications cables,
- height of trees, shrubbery, and buildings in the immediate vicinity of the power lines.

Land survey and height maps are prepared for the area within 30 m to 120 m from the axis of the towers (depending on the voltage of the given power line), coupled with longitudinal profiles of the cable route.

For the control measurement of cable sags, trigonometric correlations of the measured vertical angles and length measured at ground level are used. Based on the conducted measurements, spatial coordinates are calculated for the points of tower bases, points of cable suspension, and points of the maximum sag [Migas 2000].

Before measuring the sag, firstly centre point of the span must be determined, whereby we shall calculate the sag and the perpendicular line. Afterwards, from the centre point of *P* we shall calculate the vertical angles α, β and calculate the heights (elevations) of h_1 and h_2 (Figure 2) from the relationship:

$$\tan\alpha = \frac{h_1}{a}, \quad \tan\beta = \frac{h_2}{a} \tag{1}$$

The heights of cable suspension and *A* and *B* are derived from a simple principle of trigonometric levelling:

$$H_A = H_P + i + h_1, \qquad H_B = H_P + i + h_2 \tag{2}$$

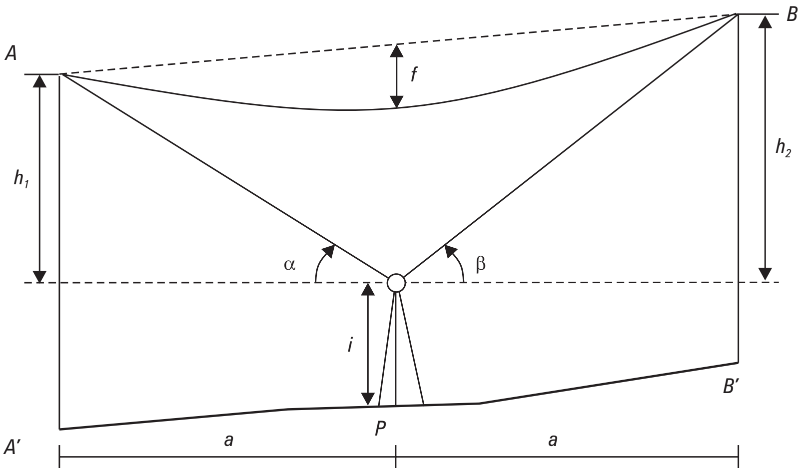

Fig. 2. Measurement of vertical angles for sag control

The height of base points of the towers *A'* and *B'* are also set using the method of trigonometric levelling, using the following formulas (Figure 3):

$$h_A = a \cdot \tan\alpha_1, \quad h_B = a \cdot \tan\alpha_2 \tag{3}$$

$$H_{A'} = H_P + i + h_A - l, \quad H_{B'} = H_P + i + h_B - l \tag{4}$$

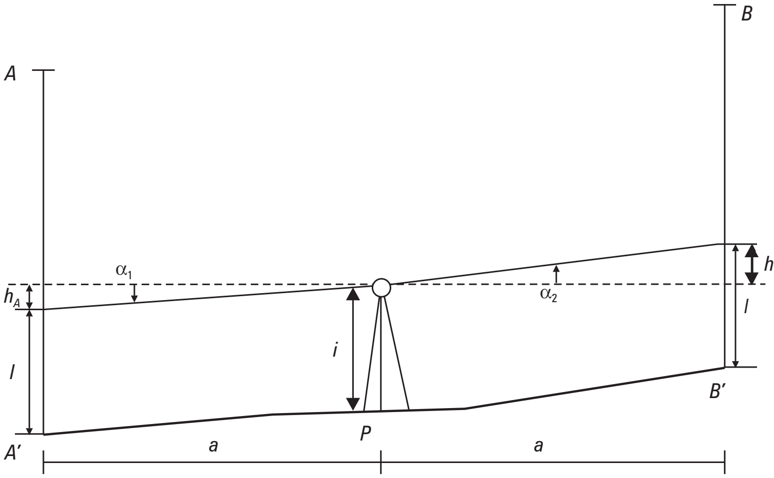

Fig. 3. Measurement of height differences in tower bases

Relative heights of h_A, h_B (3) may take either the positive or the negative sign (depending on the sign of the vertical angle α_1, α_2). The symbol *l* in Figure 3 and formula (4) denotes a certain, arbitrarily chosen, reading of the patch (for instance, $l = 1.5$ m).

Terrain conditions allowing, the heights of points of A' and B' can also be determined using geometric levelling.

The next step consists in tracing, from point *P*, a line perpendicular to the span, and thus determining point *P'*. On the line of *PP'*, starting from point *P*, we measure the value of *X* (horizontal distance of cable suspension to the centre of the span), arriving thus at the measurement point of the sag *P"* (Figure 4). The height of point *P'* is determined likewise, same as points *A'*, *B'*, *P*, using trigonometric relations or geometric levelling.

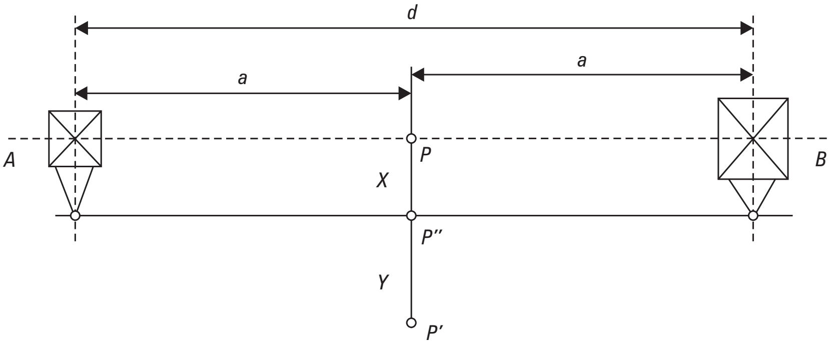

Fig. 4. Determining the point of sag measurement

We place the instrument in point *P'* and we measure the vertical angles to the cables in the vertical place of point *P"* of the cables. We derive the height of the sag from the relationship (see Figure 5):

$$H_C = H'_P + i + Y \cdot \tan\delta \tag{5}$$

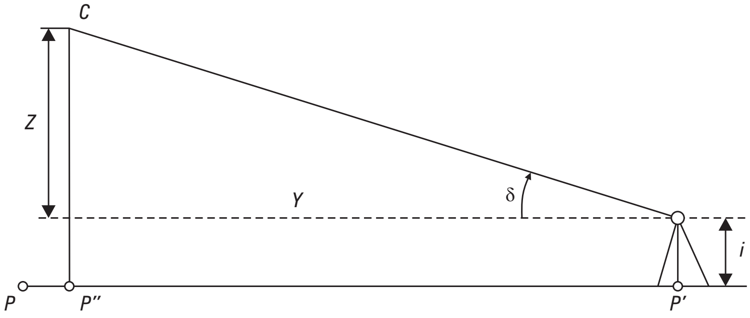

Fig. 5. Measurement of vertical angles for the control survey of cable sags

Based on the measurement method shown above, we arrive at a set of spatial coordinates of points, determining the cable sag:

- span length „*d*" from direct measurement,

- height of cable suspension *A'*, *B'* on the towers,
- height of tower bases *A*, *B*,
- height of cable sag *C*,
- height of measurement point for cable sag *P"*.

We calculate the value of the sag arrow from the following formula:

$$f = 0{,}5(H_A + H_B) - H_C \tag{6}$$

The measurement of the arrow of cable sag should be conducted twice, having additionally determined points *P'* and *P"*. The result is the mean value of both measurements. Measurements of distance, necessary for determining the sags, should be conducted using the rangefinder, which ensures the accuracy down to ±1 cm. At present, sag control is performed using available reflector-less tachymeters.

While measuring the cable sag, the temperature of the cable should be taken. As contact with the cables is not possible (they are suspended at considerable height, and they are live power wires), measurements should be conducted on a cloudy day, which shall prevent excessive cable overheating. Also wind conditions are important, as wind causes the cable to incline. Even on windless days, movement of air causes the cables to sway, therefore when measuring the vertical angle, one should make sure that the crosshairs touch the cable at the lowest possible viewpoint of the scope.

The above description of the procedures for power line control was presented in order to demonstrate the role, played in this process by the measurement stations (points of the control network).

4. Practical example

In the present work, we have used some of the observational data from a comprehensive survey, aimed at preparing a land survey and height map in the scale of 1 : 1000 (Figure 6), including the elaboration of profiles under the high voltage power line of 110 kV, up to 30 m from the axis of towers, in the area of three districts (poviats): Lesko, Sanok and Przemyśl – at the length of 79 km [Jawor 2009]. A sample fragment of the map, shown in Figure 6, illustrates the degree of difficulty of terrain conditions in the context of conducting geological surveying; the ordinates show the differences in height.

As a result of reconnaissance in the field, 4 points of detailed control network of class II and III were determined, and used as tie points for establishing the measurement network (Table 2; according to the wish of the client, the coordinates were collated in the "1965" format).

The next step was to design a classical measurement network (Figure 7). For the purpose of a comparison (with the GPS method), a 4-kilometer section of the Sanok poviat, Tyrawa Wołowska municipality, Rozpucie area was selected. It is a hilly area, with elevations up to approx. 100 m – therefore there are often limitations to views and aiming directions. Most spans are located within woodland areas, where clearance was conducted to ensure a safe distance between the cables and the trees.

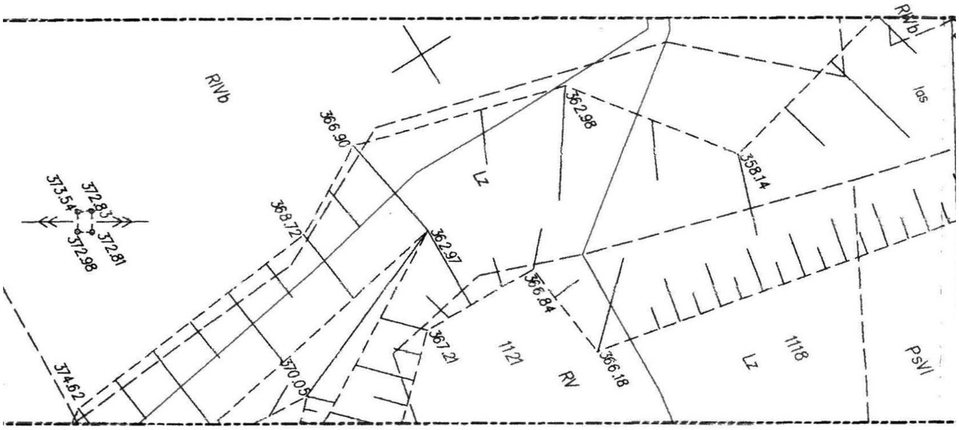

Fig. 6. A sample fragment of a land survey and height map of the area, for the purpose of power line control

Table 2. Collated coordinates of base and detailed control network ("1965" format)

Point number	Network class	X	Y
450	II	5354949.430	4731584.650
451	II	5354419.840	4732988.250
457	II	5351156.330	4731216.000
1074	III	5350907.550	4731231.980

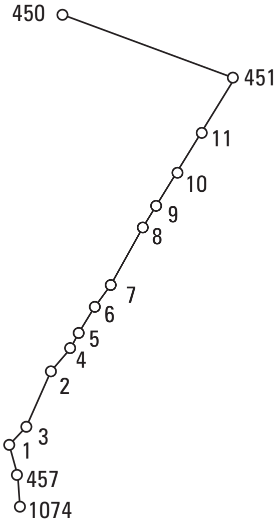

Fig. 7. Draft of measurement network points' placement

In the selected area, there are 11 high voltage transmission towers. Considering the requirement that for each span, there should be at least one measurement point, from which measurement of the situation and cable sags will be made [Migas 2000], 11 points have been designated. Measurement points have been designed in the previously marked locations, designated beforehand using GPS receivers. All points constitute a closed traverse.

As detailed control points were considerably far from each other, the length of the designed traverse exceed the permissible value (4.5 km [Regulation… 2011]) and amounted to approx. 6.533 km, with an average length of side at approx. 0.466 km. As the terrain is hilly, in some cases the designed sides of the network are larger than 600 m.

The established network was measured using the classical method (angles and horizontal distances) and using the GPS method. The measurement at points of the control network and traverse (detailed) network was effected using kinematic method in time intervals of 60 seconds, applying the NAWGEO service of the ASG-EUPOS system. For each designated point, the receiver registered signals from at least four satellites.

For the measurement of control network, the following surveying instruments were used:

- Tachymeter of the Total station type: Leica TCR 407 ultra,
- GPS receivers L1/L2 RTK VRS: Trimble 5800 and Trimble TSC2 controller.

Trimble 5800 GPS receiver combines a two-frequency GPS receiver, an antenna, a UHF radio and a power source (all in one unit). This facilitates the control of measurements without the use of cables – thanks to using short-range wireless technology (Bluetooth). The receiver may be used in many different ways – it can be set up as a portable receiver or a base station, whereby the instrument performs in changeable conditions of operation. The Bluetooth module is compatible with mobile telephone networks, which facilitates complete RTK measurements.

Trimble 5800 receiver, in collaboration with the ASG EUPOS system, uses the real time service – thanks to the principle of RTK differential positioning [Lamparski 2001] performed based on reference stations. Receivers which conduct field measurements communicate with the computing centre in order to obtain observational adjustments. The whole data exchange process happens in real time, via the GPRS Internet connection, therefore the user obtains the results directly in the field.

Results of the adjustment of traverse deviations performed using the Geonet software have been collated in Table 3. The mean error for the measurement of the angle and the distance is assumed at: 30^{cc} and 0.01 m respectively. The adjustment procedure is based on a known method of least squares. [Ghilani 2010, Wiśniewski 2005].

Resulting from the calculations, we obtained the mean error for the point location at $m_p = \pm 0{,}033$ m. The points which are most encumbered with error ($\pm 0.054 \div 0.058$ m) are those in the middle of the sequence (points 6, 7, 8).

Based on the GPS measurement, coordinates of control points were calculated in the coordinate system 2000/21 [Regulation… 2000], and then based on previously determined points of the traverse network (Table 2), affine transformation was conducted to the 1965 format in zone 1 (Table 4) [Kadaj 2000].

Table 3. Adjustment of the survey network using the classical method ("1965" format)

Point number	X	Y	m_x	m_y	m_P
1	5351398.239	4731152.241	0.016	0.010	0.019
2	5352013.415	4731492.803	0.026	0.038	0.046
3	5351556.051	4731291.085	0.026	0.029	0.039
4	5352211.133	4731646.989	0.028	0.040	0.049
5	5352334.169	4731719.613	0.031	0.044	0.054
6	5352526.992	4731841.413	0.033	0.046	0.057
7	5352726.688	4731983.328	0.034	0.047	0.058
8	5353198.272	4732245.779	0.033	0.043	0.054
9	5353371.001	4732355.921	0.031	0.040	0.050
10	5353650.740	4732534.580	0.026	0.032	0.041
11	5353975.342	4732732.032	0.018	0.020	0.027

Table 4. Coordinates of the measurement network using the GPS method ("1965" format)

Point no.	X	Y	dx	dy	dL
1	5351398.238	4731152.238	0.001	0.003	0.003
2	5352013.433	4731492.804	−0.018	−0.001	0.018
3	5351556.050	4731291.080	0.001	0.005	0.005
4	5352211.150	4731646.990	−0.017	−0.001	0.017
5	5352334.180	4731719.610	−0.011	0.003	0.011
6	5352526.999	4731841.408	−0.007	0.005	0.009
7	5352726.691	4731983.322	−0.003	0.006	0.007
8	5353198.278	4732245.776	−0.006	0,003	0.007
9	5353371.002	4732355.917	−0.001	0.004	0.004
10	5353650.739	4732534.577	0.001	0.003	0.003
11	5353975.340	4732732.030	0.002	0.002	0.003

In the presentation of results (in Table 4) deviations of coordinates were also listed (*dx*, *dy*) as well as line deviation (*dL*) compared to the results from the classical measurement method (Table 3). We immediately observe that the differences are only slight; the maximum line deviation does not exceed 2 cm (for points 2 and 4). As these values are far below the location errors in the classical method (which ranged around ± 5 cm, compare Table 3), we can conclude that the GPS method is sufficient for obtaining the desired accuracy.

5. Conclusions

In the present work, we discussed the role of geodetic control network, established for the purpose of monitoring the location of power lines. The task constitutes a particular application of survey measurements. Appropriate control (for instance, determining span length or cable sag) requires a correct design and establishing a measurement network. We have noted the aspect of accuracy of situational location of points, based on the RTK GPS method. For the analysis, we have used a certain subset of data for a real-life object (high voltage power line at the distance of 79 km). For comparative purposes, classical situational survey of the network was conducted, using the Total Station type instrument.

For GPS measurements, modern receivers (Trimble 5800) were used as well as options offered by the ASG-EUPOS system of reference stations, coupled with the NAWGEO service.

Particularity of the task consisted – among other things – in selecting the optimal measurement method for difficult terrain conditions. In this context, the RTK GPS method turned out to be decidedly more comfortable and more efficient, and the results it rendered were not substantially different (in terms of accuracy) from those rendered by the classical method. In the case of difficulties in obtaining the proper exposure of the measurement station to satellite signals (for instance, in a woodland area), we propose that the GPS measurement be supplemented with classical methods. Of course, the best solution would be to apply an integrated measurement method (both classical and GPS). That, however, would require an appropriate preparation of observations at the stage of numerical analysis of results (consisting in bringing different types of observation down to one mathematical model [Gargula 2009]). This latter issue will be the topic for further studies into geodetic control methods of power lines.

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