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The Update of a Land Survey and Height Map for Design Purposes with the Use of the RTK GPS Technology**

1. Introduction

The RTK GPS (Real Time Kinematic Global Positioning System) is becoming a common survey method used in various geodesic works. Particularly with reference to a land survey and a height map update for design purposes, it is an effective technology and it enables obtaining a survey results promptly with a required precision. Each land surveyor who performs the land and height surveys, has repeatedly been convinced, how burdensome and time-consuming the assignment of a survey position in establishment with geodetic bench marks in tachographic measurements are. Meanwhile, some variants of RTK GPS technologies of conducting the measurement enable considerably to restrict the necessity of using the geodetic bench marks in a classical points form. A grid of reference ASG EUPOS stations, which are systematically developed, and according to the plan should operate in the whole country from the second half of 2008, would contribute in a great measure. Thus, on the other hand, performing a direct land survey with the use of RTK GPS technology is hindered or even impossible with reference to situation details not easily accessible in respect of satellite signal reception. As mentioned above, the purpose of the thesis is, among other, to present various solutions of the above details surveying.

2. Variants of the RTK GPS Survey Performing and Establisment

The essential RTK GPS survey part is a proper selection of geodetic bench mark points used as base station posts or as transformation adjustment points.

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The ASG EUPOS reference stations' network is an alternative to geodetic bench marks. With the network in range, a problem of establishing the base station fades completely, because its function is transferred to a permanent station.

In connection with the above, one can isolate the following RTK GPS technology survey establisment cases:

1) There is a possibility of using a reference station which is a part of ASG EUPOS, with the function of a base station. In this case a survey equipment is reduced to one receiver (mobile). It has to be equipped with a corresponding software, which ensures the corrections' transmission from a permanent station to a receiver (ie. mobileNtrip). The transmission of the data can be realised in a direct way – most often with the use of a digital telephony. The other way of corrections' transmission is to utilize so called virtual reference stations. Data from a permanent station is in this case transferred to a Control Centre, where regional corrections are defined. Next, through a continuous data transfer between Control Centre and a mobile receiver (rover), mobile receiver's localisation data and corrections is updated and so called virtual reference station (VRS) is generated. It is usually located in a distance of a few metres from a mobile receiver, and all data transmitted from a Control Centre to the rover is received in such a way, as they were to be transmitted from an actual base station in the Rover's neighbourhood.
2) A lack of reference station and a necessity to use the existing geodesic bench marks.

Practically two cases, which determine the usage of geodesic bench mark point to Φ, Λ, h ellipsoidal coordinates transformation to flat systems, ie. "1965" or "2000" can be distinguished.

Base station as an unbounded stand

In this case the Φ, Λ, h geodetic coordinates of this stand are determined with a navigational precision. However, in the same time the mobile receiver performs survey on existing bench mark points of known "1965" system coordinates (adjustment points), assigning also its ellipsoidal coordinates (Φ, Λ, h). Practically to obtain a required precision of land and height survey, the adjustment point quantity should be no lesser than four. Basing on the survey, transformation coefficients are calculated. After these activities one can enter the direct terrain details' survey with the RTK GPS technology, obtaining results (situation details coordinates) in a "1965" system.

Base station is localised on a geodesic bench mark point

In this case, one is confined to set the base station on a bench mark point and make an entry of ellipsoidal coordinates of this point and rectangular coordinates, ie. in “1965” system to the receiver. Having the mobile receiver equipped with the software which enables the transformation of coordinates between systems at the disposal, one can approach a land detail survey in a real time.

3. The Update of a Land Survey and Height Map in the Field with the Use of the RTK GPS Technology

According to a decree of the Ministry of a Spatial Economy and Construction [5], a design of a plot or terrain development should be performed on a copy of a up-to-date land survey and a height map. A double reduction or magnification of the map is allowed. Basing on § 5 of this decree, maps made for designing purposes, should enclose the territory which surrounds the investment area in a strip of at least 30 m.

Whereas the content of a map for designing purposes according to § 6 of the above mentioned decree, should contain elements of land survey and a height map’s content and other elements listed in this decree, such as:
- geodesically determined lines delimitating terrains of different destination, building lines and street and roads’ axis, etc.,
- localisation of tall greenery and indication of nature monuments,
- localisation of other objects and details advised by a designer, in accordance with a purpose of performed work [5].

During the update of a land survey and a height map for design purposes, apart from used technology a positional – height measurements should be carried out with the necessary control measurements on the specified area. The control measurement encloses determining the localisation of terrain details existing on the map (ie. buildings’ and fences’ corners, etc.).

Knowing the design’s character, in certain cases also a ground-based elements of underground territorial development measure is advisable, independently apart from the fact of its appearance on a base map. It will ensure a proper connection of the designed object to existing territorial development networks and will allow to eliminate possible mistakes linked with the previous measurement and charting these elements on the map.

The classical measurement technology, used in the update of a land survey and a height map for design purposes is a tachometer survey. However, as mentioned in the introduction to the article, the most labour-consuming task for the land surveyor is to determine a proper localisation of survey stands in establishment with existing geodesic bench marks. The best solution for cases, in which a problem of a geodesic bench marks localisation occurs, is the use of the RTK GPS technology to determine survey stands and establishment points.

Before commencement of the RTK method survey a measurement of so called control point should be performed, which is a point of known rectangular coordinates in "1965" system or "2000" X, Y, H system [8].

Such measurement is a control of the receiver set and has a purpose of checking:

- the proper receiver's initialization,
- properly entered antenna height and proper level indication,
- proper progress of corrections transmission,
- correctness of a accepted coordinate system model basing on calibrating by adjustment points.

There are no obstacles to use a real time survey method for determining a terrain details' localisation as well. As mentioned in the introduction to the article, occurrence of some difficulties connected with described details' measurement method is still possible, ie. skyline blank off could happen because of terrain obstacles occurrence (buildings, power line towers, trees, ravines, bushings), which makes the signal transmission to the receiver impossible.

However, the usage of proper measure techniques, an efficient and required accuracy-preserving coordinates determination is still possible, even of not easily accesible terrain station poles.

It seems, that one of the most difficult to assign by the RTK GPS method situation details of I-st accuracy group are buildings' corners. To determine them, indirect methods illustrated on figures 1–3 can be used. These methods were ranged in an accquired accuracy of a situation detail determination order.

A measure of these station poles is based on points determined in a real time with the use of the RTK GPS, which exists as successive base points for other measure technologies, which lead to a direct determination of situation details' coordinates.

Basing on the accuracy analysis held in [1], a couple of indirect measure methods could be proposed, which lead to assigning station pole's coordinates. In figure 1 a point on a straight line method is illustrated, which allows to get the highest accuracy of indirect determination of situation detail's localisation.

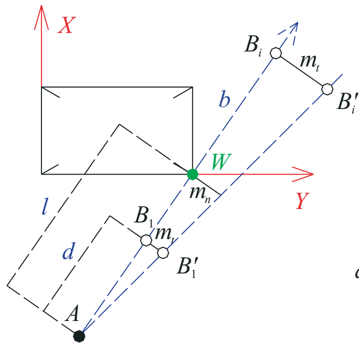

Fig. 1. Determining of not easily accessible terrain details with the use of an indirect measure method – point on a straight line

Point on a straight line method

After compensation of *l* and *b* section lenghts relatively to the base AB section length, obtained from *A*, *B* points' coordinates, we can enter the *W* building's coordinates calculations:

$$X_W = X_A + l\cos A_{AW}$$
$$Y_W = Y_A + l\sin A_{AW} \tag{1}$$

where

$$A_{AW} = A_{AB} = \operatorname{arc\,tg}\frac{Y_B - Y_A}{X_B - X_A}.$$

Deviation of *W* point localisation will be determined by applying Gauss' law of flux (law of deviations' transfer) to functions given by the equation (1). For that purpose, partial derivatives will be calculated $\frac{\partial X_W}{\partial X_B}, \frac{\partial X_W}{\partial Y_B}, \frac{\partial X_W}{\partial l}, \frac{\partial Y_W}{\partial X_B}, \frac{\partial Y_W}{\partial Y_B}, \frac{\partial Y_W}{\partial l}$,

and succesive average deviations:

$$m_{X_W}^2 = l^2\left(\frac{(\sin^2 A_{AB})^2}{d_{AB}^2} m_{X_B}^2 + \frac{(\sin 2A_{AB})^2}{4d_{AB}^2} m_{Y_B}^2\right) + \cos^2 A_{AB} m_l^2 \tag{2}$$

$$m_{Y_W}^2 = l^2\left(\frac{(\sin 2A_{AB})^2}{4d_{AB}^2} m_{X_B}^2 + \frac{(\cos^2 A_{AB})^2}{d_{AB}^2} m_{Y_B}^2\right) + \sin^2 A_{AB} m_l^2 \tag{3}$$

It should be noted, that m_{X_B} and m_{Y_B} parameters result from ranging deviations (matching) of *B* point on *A*–*W* line (or its lengthening), not from the point's RTK GPS technology measure deviation.

Presently, having used the equation $M_P^2 = m_{X_P}^2 + m_{Y_P}^2$ and replaced m_{X_B} and m_{Y_B} with dependences resulting from trigonometrical functions connected with parameters presented in figure 1, we can state, that:

$$\begin{aligned} m_X &= m_t \sin A_{AW} = m_n \frac{d}{l} \sin A_{AW} \\ m_Y &= m_t \cos A_{AW} = m_n \frac{d}{l} \cos A_{AW} \end{aligned} \tag{4}$$

Basing on the above analysis, a final *W* point localisation deviation's value will be determined

$$M_{P_W} = \sqrt{(\sin^4 A_{AW} + \cos^4 A_{AW})\, m_n^2 + m_l^2} \tag{5}$$

Basing on the equation (5), we can form a statement, that forming of *W* point localisation deviation is conditional on *A–W* (m_n) direction's azimuth and accuracy of its assignment, and also on m_l linear measure's deviation. Forming of M_P deviation in dependence on equation (5) parameters was presented in table 1.

Table 1. M_P average fault forming

	A_{AW} = 45° or 135°			A_{AW} = 850° or 1750°		
	m_1 [cm]			m_1 [cm]		
	1	2	3	1	2	3
m_1	M_P [cm]			M_P [cm]		
1	1.2	2.1	3.1	1.4	2.2	3.2
2	1.7	2.4	3.3	2.2	2.8	3.6
3	2.3	2.9	3.7	3.1	3.6	4.2
4	3.0	3.5	4.1	4.1	4.4	5.0
5	3.7	4.1	4.6	5.1	5.4	5.8

Analysing calculation results presented in the table 1 it can be noticed, that the average fault M_P of *W* point localisation is getting lower, when direction's azimuth changes from 85° to 45°. However, intependently from a quantity of parameters, which influences the forming of the M_P deviation, the accuracy of building's corner localisation (*W*) does not exceed an admissable deviation provided for terrain details from I-st accuracy group. As mentioned above, we can assume, that the discussed method of the point on a straight line can be well used to an indirect determination of coordinates of building's corners.

Linear intersection method

Figure 2 presents a method of linear intersection with a graphical analysis of *W* point determination accuracy.

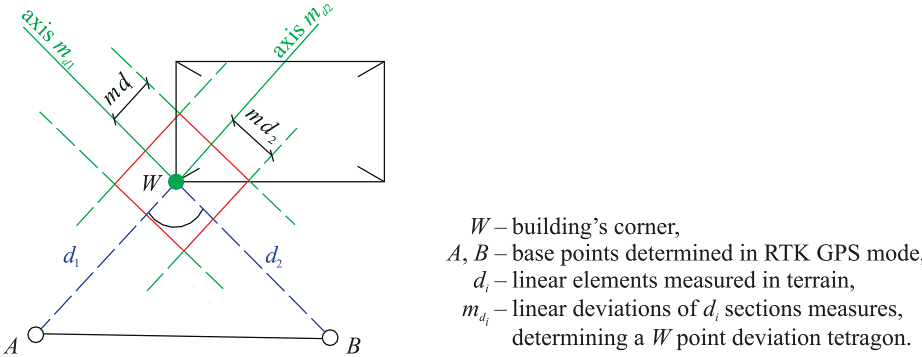

Fig. 2. Determining of not easily accessible terrain details with the use of an indirect measure method – linear intersections

Results of graphically presented accuracy appraisal could be confirmed by conclusions arising from valuation realised in analitical mode, basing on the equation

$$M_p = \pm \frac{1}{\sin(\alpha + \beta)} \sqrt{m_a^2 + m_b^2} \tag{6}$$

After assuming, that sides *a* and *b* are saddled with an equal linear deviation $m_a = m_b = m$ we will get a final equation for calculating an average deviation of incision point localisation.

$$M_p = \pm \frac{m\sqrt{2}}{\sin(\alpha + \beta)} \tag{7}$$

According to the equation (7), the exactitude of linear deviation point localisation determining depends on the value of incision angle and the accuracy of linear measurement. When the angle increases from 0° (theoretically) to 90°, the value of deviation will tend to minimum for $\sin(\alpha + \beta) = 90°$, $M_p = m\sqrt{2}$. With the further incision angle's increase from 90° to 180°, the M_P localisation deviation will increase from the minimal value to ∞ (theoretically). According to the above, the M_P deviation variation is to be concerned while the practical usage of linear incision.

In the table 2 the influence of the angle's value on M_p variation is presented (when $m_{d1} = m_{d2} = m$).

Table 2. Influence of the incision angle's value on M_p point localisation mean deviation

					boundary value
m = 1 cm	Incision angle	90°	45° or 135°	22.5° or 157.5°	8° or 172°
	M_p	1 cm	2 cm	4 cm	10 cm
m = 2 cm	Incision angle	90°	45° or 135°	22.5° or 157.5°	16.5° or 163.5°
	M_p	3 cm	4 cm	7 cm	10 cm

In the last column of table 2, the boundary values of incision angle are presented, where station pole localisation's deviation will not exceed a maximium value of a deviation which was stated for the I-st accuracy group of details positions, i.e. +/– 10 cm.

Straight line intersection method

On figure 3 a straight line intersection method is presented. In referrence to this method, wide accuracy analysis were performed in [1], on the grounds of which a conclusion can be formed, that this is the least accurate method from all discussed methods.

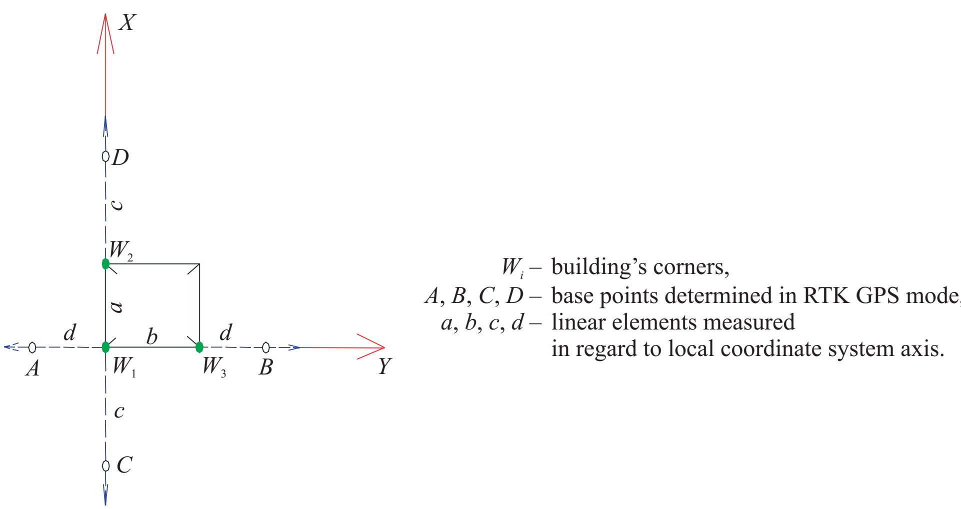

Fig. 3. Determining of not easily accessible terrain details with the use of an indirect measure method – straigh line intersection

Power and telegraph line towers can be numbered among the other group of not easily accesible terrain details in RTK GPS technology measuring. Real time measure of these objects is possible with the assumption, that there is a possibility of setting the antenna in the vicinity of a measured detail. Then it should be set in the north-south or the east-west direction. X and Y rectangular coordinates obtained this way in "1965" system will be consecutive changed in controller's editor of dX and dY increments, which are equal to directly measured linear circulars of these directions. This procedure fundamentally will not influence the decrease of measure's accuracy. A particular attention should be paid though to a possibility of satellite signal reflections occurrence in vicinity of this type objects.

Difficulties, which can arise during the real time measuring, and certain inconvenience of tachometer method incline to develop new solutions which merge advantages of both methods. Geodesic companies develop different technological solutions merging satellite method with tachometer detail measure method basing on the usage of electronic tachometers integrated with GPS receiver. The example of this solution can be ie. Leica SmartPole System. It consists of three elements: Leica TPS1200+ tachometer, integrated GPS RTK Leica SmartAntenna ATX1230 receiver installed on the pole with 3600 prism and a RX1250 controller [7].

4. Verifying of Accuracy Analysis of a Real Terrain Object

Terrain object, on which the RTK GPS technology usage was verified to update a land survey and a height map, is located in silesian voivodeship in Kozy community. It comprised an area of circa 20 ha of a diversified profile. 1:1000 scale map update was performed for the object with the use of two measure technologies: the pole method and the RTK GPS method. For the pole measure TC 600 electronic tachometer was used, whereas, in the RTK technology, Z-Surveyor double-frequency receivers produced by Ashtech and HUSKY controller were used. Equipment used in measures was additionally provided with IPAQ H 3850 palmtop. Using a palmtop in measurements allowed limiting of a number of bench mark points. In this case only one bench mark point location was sufficient for an area specified by a reference station range. There was no need of choosing adjusting points, while measure equipment used was equipped with proper software, which completed a transformation of directly measured ellipsoidal Φ, Λ, h coordinates to "1965" system rectangular coordinates.

Terrain pickets, which were measured with the use of both methods, are most often met among I-st accuracy group objects. They are: apartment and farm buildings' corners, stairs, retaining walls, fencing's corners, decanters, power and telegraph line towers, drive-in gates, wells, asphalt roadway's curbs.

To determine some of the above mentioned elements with the use of RTK GPS technology indirect methods of determining not easily accessible terrain details were used, which were described in this elaborate. Most often it concerned buildings' corners, which were qualified as separate details' group (so called *A group*) made subject to analyze of measure results. Approximately 500 terrain pickets were jointly measured, where 126 of which were apartment and farm buildings' corners (so called A group of terrain details), and remaining 217 were situation pickets (so called B group of terrain details) except for roads and ravine.

For so called A group of terrain details the X and Y horizontal coordinates were determined. For every measured terrain picket coordinates obtained from the pole method measure were compared with coordinates obtained from a real time measure, having differences in dX and dY. Average coordinate difference values (measured from absolute values) are presented in table 3.

Table 3

	dX [cm]		dY [cm]	
terrain details A group	**average** max. min.	**4.1** 39.8 0.2	**average** max. min.	**9.9** 27.3 2.6

To show the forming of coordinates' differences diagrams illustrating a frequency of dX and dY values occurence were drawn up in particular ranges (Fig. 4).

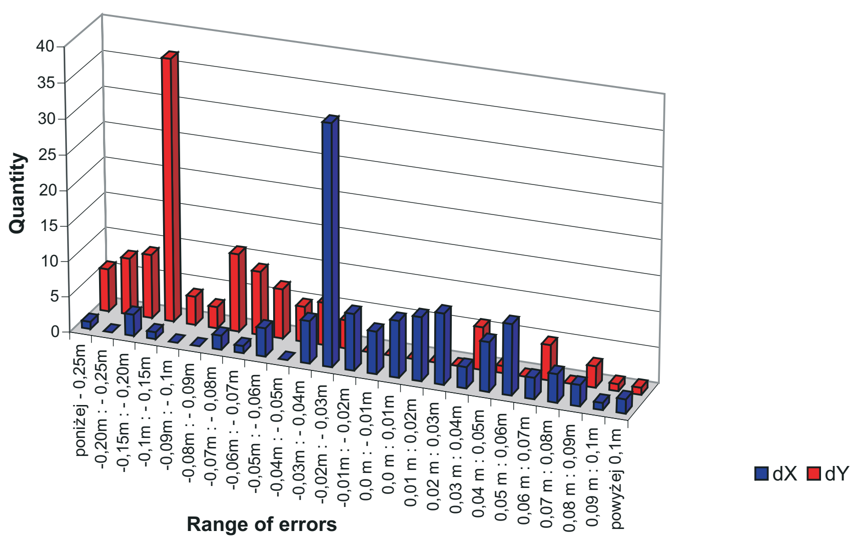

Fig. 4. Frequency of dX and dY differences occurence in particular value ranges for buildings' corners

By the analysis of a diagram presented on a figure 4 one can observe, that the dX coordinates' differences shape between a pole method and a RTK GPS is on a level of 2–4 cm. Results of Y coordinates comparison look slightly different, for them dY shapes within limits of 10 cm. One should remember though, that coordinates determined in a pole method are also saddled with a deviation. Therefore, they are not of standard values for results of other measuring technologies. The influence on the arisen coordinates' differences could have the following factors: detail measure basing on various ways of measure control to the bench marks, various measure station locations in both methods.

By the analysis of average values of dX and dY coordinates' differences (Tab. 2), which range in the level of +/– 4–10 cm for buildings' corners, we can state, that indirect methods of determining of not easily accessible terrain details are suitable for measurements with a purpose of updating the land survey and a height map with the use of the RTK GPS technology. One should always remember that base points for indirect measurement methods should be determined with possibly minimal deviation. Preserving maximum measure accuracy during the use of these methods, which can be acquired by measured section's linear deviation's minimalisation (ie. with linear intersection), a base point matching deviation on a proper straight line and an adequate proportion of prolonged line to the lengthened line, etc.

5. Land and Height Measure Survey Prepared with Use of the RTK GPS Technology

Each geodesic measure survey should be completed in accordance with guidelines included in O-3 instruction [2]. In case of surveys prepared on the grounds of RTK measures, each of its capacity should be updated of additional documentation specific to this measure technology. As for today, there are no unequivocal guidelines in the country scale, that precise a content of these additional documents. These guidelines are in elaboration phase by GUGiK.

Basing on guidelines for Małopolskie voivodeship, additional content of particular survey's capacity referring to RTK GPS technology should appear as following:

- ZB base capacity:
  - Technical report with a detailed description of RTK GPS measure data (ie. a type of receiver and antenna, software, origin of recalculation coefficients and transformation method, a type of correction used).
  - Bench marks' draft, containing points of adjustment to local rectangular coordinates systems and a location of control point.

  - Table of flat rectangular coordinates of control point differences (given and measured).
  - Table of *X*, *Y*, *H* picket coordinates differences in rectangular system obtained in a double measure, for which an additional assign certitude should be adopted (ie. border points).
- ZU use capacity:
  - Table of *X*, *Y*, *H* coordinates in „1965” or „2000” system of all measured points.
- OT temporary capacity:
  - Field record of satellite observation for control point and terrain pickets (point no., measured height, measure date and time, data record interval).
  - Field drafts of measured terrain details.

All coordinates indexes and coordinate differences should be given in the national or local system and in the system which is realised by reference stations [6].

6. Summary

Nowadays, in a line of geodetics we can observe more and more rapid development of using modern measuring technologies. The RTK GPS method becomes a commonly used measuring technique, too. It is brought about, among others, by economical and precision conditions. This method enables an efficient and accurate survey operation with the engagement of a small measuring team, and the price of the RTK GPS set is systematically decreasing, what encourages geodetics companies to invest in a modern hardware. The startup of ASG EUPOS reference stations network in the whole country planned for 2008 will become an additional advantage.

The RTK GPS method enables performing geodetics measurements of situation details even in case of a no sufficient number of bench mark points available in terrain to establish a classical tachometer measures. Skilfully merging the RTK GPS technology with classical geodesic surveys, we can determine a localisation of all terrain details with a satisfactory accuracy.

Operating a land and height works with the use of a real time survey method is rendered difficult in a greater degree by a lack of unequivocal regulations related with technical design elaboration for ODGiK. Merely a couple of ODGiK’s in the scale of the whole country dispose of guidelines to measure survey elaborating prepared in a local territorial range. Moreover, ODGiK’s employees are still not properly trained in a discussed scope, what hinders cooperation with contractors repeatidly. We should hope thus, that with ASG EUPOS network startup, technical guidelines connected with geodesic survey and results elaboration would be updated of a part specific to the RTK GPS technology.

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