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Analysis of RTN Measurement Results Referring to ASG-EUPOS Network

1. Introduction

In June 2008 ASG-EUPOS network system, implemented within the European project called European Position Determination System, was made available to users in Poland. For surveyors an interesting product of the ASG-EUPOS network system appears to be the NAWGEO service, whose accuracy in determining horizontal coordinates of points was defined as not worse than 3 cm and the accuracy in determining the heights as not worse than 5 cm, with a confidence level of 99.9% [6]. The main objective of this work is to verify this information. For this purpose, RTN measurements (Real Time Networks) were conducted, with the use of the RTCM 3.1 protocol as, until that moment, it was the protocol used by most users (81%), according to statistics provided in [6]. An important aspect of the applied testing technology was a project of test points location as well as the use of precise terrestrial surveys to control the quality of the reference coordinates of the test points, calculated from GPS static surveying. In case of using precision instruments for terrestrial surveying, it is possible to obtain accurate measurements of distance and height of less than 1 mm. The conclusions from the tests were based on the 4475 RTN measurements of 27 points.

2. Test Points Surveying

The location of the test points was designed in such a way that they were at 3 different directions from the KRAW station in Cracow. Points at a given direction were stabilized in 3 groups remote from the KRAW station sequentially by about 12 km, 21 km and 35 km. Each group consisted of 3 points stabilized in the

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reciprocal distances of several to 105 meters, with keeping aiming directions between them. Extreme distances between the KRAW station and groups of test points were chosen on the border of the correct vector solution with respect to the physical reference station (Single Reference RTK) and the maximum distance of the determined point from the reference station of the then designed ASG-EUPOS network system. The measurement mark for all points were stainless steel bolts of the length of 80 mm. The stabilization took place through the casting of a drilled hole with an epoxy resin, and the location of the measuring mark there. A location sketch of the test points and the reference stations used in the calculations, together with the vectors of static GPS surveying are presented in figure 1.

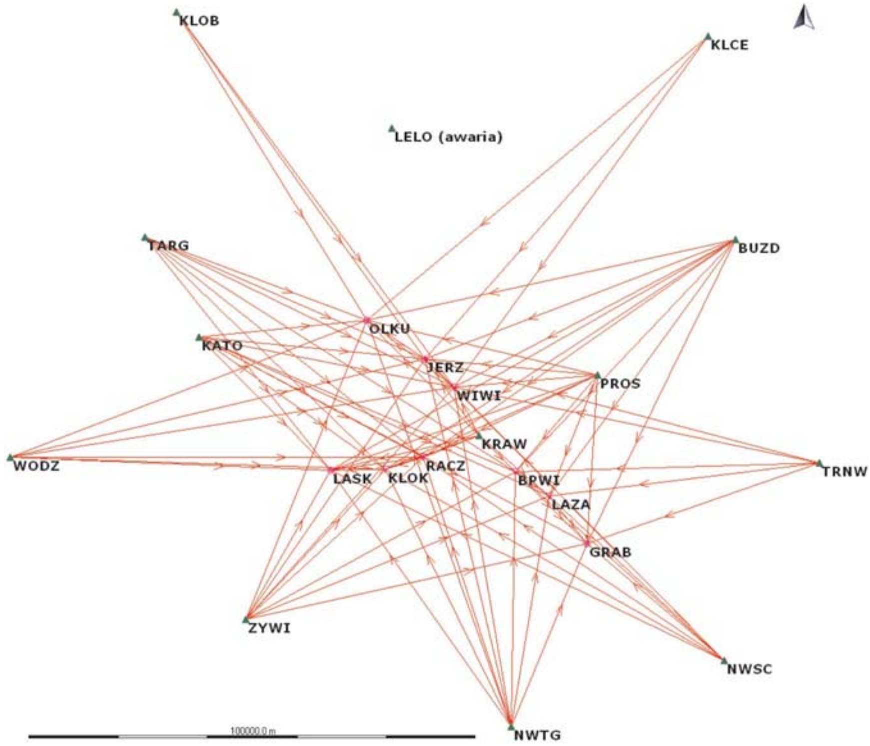

Fig. 1. Sketch of the test points and the ASG-EUPOS reference stations, along with GPS vectors

Static GPS, tachymetric, precise levelling and the RTN measurements were carried out for the test points. The reference coordinates of the test points for the RTN measurements in the WGS-84 system were based on 3 static GPS sessions, carried out simultaneously with 9 receivers made by Leica company: 3 SR399E receivers, 1 SR9500 receiver, 3 SR530 receivers and 2 GX1230GG receivers. During a specific session, all the points which were located at one of the three directions from the KRAW station were covered. These static GPS sessions lasted from a minimum of 7 up to 10 hours. For the total station surveying, a precise instrument TCA2003 of the angular measurement accuracy of 0.5″ and the distance measuring accuracy of 1 mm + 1 ppm was used. The surveying was performed in 3 series. The precise levelling was conducted with the DNA03 code leveller, characterized by the standard deviation of height measurements of 0.3 mm/km, with the use of invar staff. The RTN measurements, the results of which were the main subject of the analysis, were carried out using the GX1230GG receiver equipped with a Siemens MC75 modem. Only the NAVSTAR GPS satellite signals were used due to technical limitations of the ASG-EUPOS.

For each of the 27 test points the surveys were conducted, using the following Mountpoints of the NAWGEO service:

- RTCM_3_1_MAC (Master Auxiliary Concept), NMEA-GGA – yes,
- RTCM_3_1_VRS (Virtual Reference Station), NMEA-GGA – yes,
- RTCM_3_1_POJ (the nearest reference station), NMEA-GGA – yes,
- RTCM_3_1_MAC at the selection of the VRS (MACvrs) Network Solution in the GPS receiver in Ref. Network option.

A series of 30 surveys, each lasting an average of 6 one-second periods with respect to the above-mentioned formats of corrective amendments and virtual observations was performed during the surveying procedure. After the survey at the third point, which was the last one in the group, a re-survey was carried out at the point which was surveyed as the first one in the group, using the VRS observations and the MAC data (observations of the main station and corrections to the auxiliary stations), as most used by the users. In total, 4475 positions of 27 test points in the 149 surveying series were determined. In several cases, there were slightly above 30 designated positions in the series. In contrast, for the point RACZ01, the series of repeated VRS surveying comprised 26 positions due to the emergence of the problem with the availability of data from the ASG-EUPOS network at about 16:20 hours. Problems with the possibility of determining the test point position using the corrections of the ASG-EUPOS network emerged each day of the test surveys. The most frequent and longest breaks during the RTN measurements occurred from 10:00–13:00 hours and they always concerned the VRS observations, and frequently the MAC data; it also happened that no surveys could be performed. Problems with the ASG-EUPOS data also emerged at other times.

All surveys were conducted using wooden tripods, and the centring was carried out with the use of precise optical plummets.

Terrestrial surveys were the basis for determining the quality of the reference coordinates of the test points, calculated from the static GPS surveying.

3. Analysis of Quality of Reference Coordinates for the RTN Measurements

A key issue in the tested accuracy of determining the position of the points from the RTN measurements with respect to the ASG-EUPOS reference stations was to determine as exact coordinates of the test points from the static surveying as possible, due to the fact that these coordinates acted as reference when comparing the coordinates obtained from the RTN measurements. The calculations of satellite, levelling and tacheometric surveying were conducted in Leica Geo Office v. 7.0 [3]. The normal heights of the points were determined based on the model Levelling Geoid 2001 as well as measured differences in heights between the points.

The assessment of the quality of static surveying and the quality of the coordinates calculated on these grounds was based on the analysis of the postprocessing results as well as the adjustment of GPS vectors, the comparison of the reduced lengths of the GPS vectors and the reduced TCA2003 total station survey results, the comparison of the differences between ellipsoidal heights and the results of precise levelling with the use of DNA03 instrument. The post-processing of static satellite observations was preceded by the acquisition from the NGS [7] website of precise satellite orbits and the GPS antenna calibration parameters set over the reference points of ASG-EUPOS network, which were used in the surveying, as well as the GPS antennas used in the test surveys.

On the basis of the results of the adjustment of the GPS vectors from the static surveying, the quantities characterizing the quality of the coordinates of the test points were analysed: the standard deviations of the coordinates were comprised in the range of 0.3 mm to 0.8 mm, the quality of the coordinates calculated on the basis of variance-covariance matrix [3] was at the average level of 2.3 mm. The analysed parameter of the adjustment of the GPS vectors was also external reliability, which can be described as the most powerful influence of an error which was not detected in the observations at a given coordinate [3, 5]. Its values for the coordinates in the directions of east – west and north – south did not exceed 0.9 mm, and the external reliability for height did not exceed 2.0 mm. This demonstrates a very high "sensitivity" of statistical tests in the detection of errors in the coordinates of points. The analysis also uses classical surveying results, which for the GPS surveying may be regarded as virtually faultless. The calculated lengths of the GPS vectors and the corresponding distances from the surveys conducted with the TCA2003 instrument were compared. Out of 27 cases, in 14 of them these differences were smaller than 1 mm, while in the remaining 13 they did not exceed 2 mm.

The ellipsoidal heights were calculated from the satellite surveying. Based on the model Levelling Geoid 2001 it was possible to determine the normal heights for the test points. The precise levelling became the base for the calculations of the differences in heights between the points in a specific group. For one of the points in a specific group, a normal height from the model Levelling Geoid 2001 was determined, and the heights of the remaining points were determined on the basis of the measured differences in heights measured with the use of the DNA03 digital leveller. The values of the differences between differences in heights of ellipsoidal points from the STS GPS surveying and the differences in heights by levelling (1) did not exceed 2.2 mm.

$$Dh = Dh^{\mathrm{DNA03}} - DH^{\mathrm{STSGPS}} \tag{1}$$

The analysis of the results leads to the conclusion that the determined coordinates of the test points from satellite static surveying may be considered to be accurate and might be used as reference coordinates for the comparison with the coordinates from the RTN measurements.

4. Analysis of the RTN Measurement Results

The result of the RTN measurements was determining of 4475 positions of 27 test points in 149 surveying series. The subject of the analysis was the precision and accuracy of the coordinates calculated by the GX1230GG receiver on a database of the ASG-UPOS network from the NAWGEO service.

The precision of the horizontal coordinates of the points from the RTN measurements must be assessed as high. Specification of the extreme values of the differences in particular coordinates and the value of their standard deviations in the analysis of the whole surveying precision have been contained in table 1. More complete information about the surveying may be obtained from a chart drawn up for 4475 points (Fig. 2a), after removing one blunder-sized error measurement (values of differences of coordinates, in mm [dY, dX, dZ] = [28, –33, –58]). The error occurred when an automatic change of the reference station took place in the RTCM_3_1_POJ service, from KRAW to PROS. It was the only such case in all surveys.

The precision for the entire sample test for horizontal coordinates ranged from 0.015 m to 0.016 m. However, the vast majority of the results was characterized by the precision not worse than 5 mm (Tab. 2). Twice the range of the precision of heights in relation to the range of horizontal coordinates confirms the generally formulated relationship of accuracy of these coordinates.

Table 1. Value range of coordinate differences in the analysis of precision

Statistic [mm]	Δ*Y*	Δ*X*	Δ*Helips.*
Min.	–15	–15	–27
Max.	14	16	33
St. deviation	2	4	6

Table 2. Frequency and percentage of the coordinate precision within certain ranges

Coordinate	Δ*Y*		Δ*X*		Δ*H*	
Range [mm]	Number	%	Number	%	Number	%
±5	4301	96.13	3872	86.54	3047	68.10
(–10, –5) and (5, 10)	159	3.55	520	11.62	1008	22.53
(–20, –10] and [10, 20)	14	0.32	82	1.84	384	8.58
(–30, –20] and [20, 30)	0	0.00	0	0.00	30	0.67
(–40, –30] and [30, 40)	0	0.00	0	0.00	5	0.12

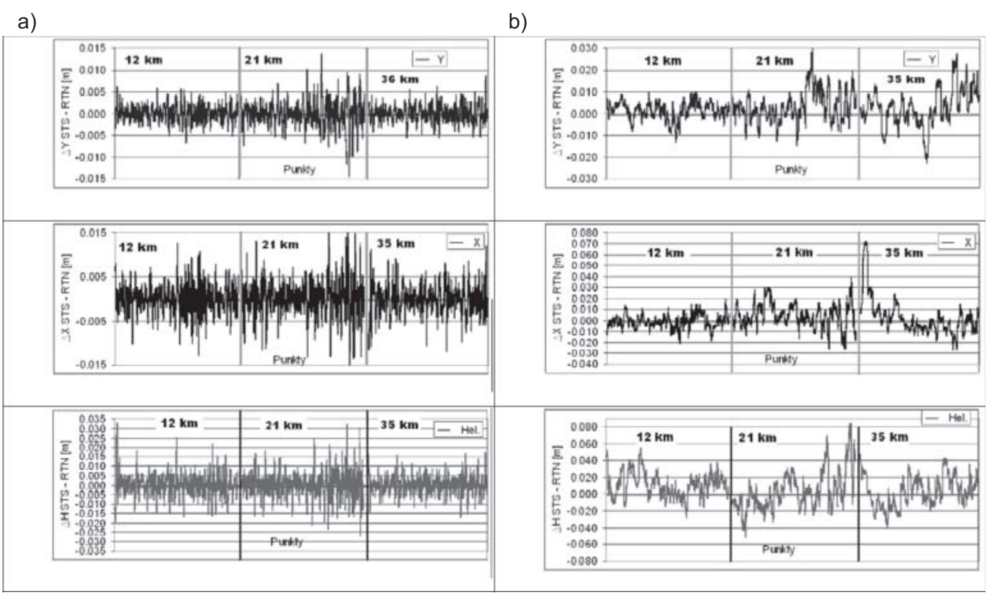

Fig. 2. Precision (a) and accuracy (b) of RTN Position sorted by distance from the nearest reference station

Inclusion in the analyses of the exact coordinates calculated from the STS GPS surveying analysis enables to determine the accuracy of the coordinates from the RTN measurements. Figure 2b shows the accuracy of determining individual coordinates for all surveys. A significant increase in the values of differences of coordinates in relation to the precision is apparent. The average value (Tab. 3) indicates a small systematic factor for the horizontal coordinates and somewhat larger for the heights.

Information from the RTN measurement accuracy histograms are contained in table 4. In the case of the *X* coordinate there is a clear systematic error. There is zero incidence of occurrences in the range of (±40)–(±50) mm for 60 surveys of even less accuracy. A detailed analysis of the 149 surveying series revealed the whole 6 series of blunder heights standing out from the average, including the 3 series, in which the horizontal coordinates were also blunder errors.

Table 3. Value range of coordinate differences in the analysis of accuracy

Statistic [mm]	ΔY	ΔX	$\Delta Helips.$
Min.	–23	–27	–53
Max.	30	72	84
St. deviation	7	12	19
Mean	2	2	6

Table 4. Frequency and percentage of the coordinate accuracy within certain ranges

Range [mm] \ Coordinate	ΔY		ΔX		ΔH	
	Number	%	Number	%	Number	%
±5	2834	63.34	2053	45.89	845	18.9
(–10, –5) and (5, 10)	981	21.93	1176	26.29	930	20.8
(–20, –10] and [10, 20)	570	12.74	909	20.32	1471	32.9
(–30, –20] and [20, 30)	89	1.99	264	5.90	701	15.7
(–40, –30] and [30, 40)	0	0.00	12	0.27	309	6.9
(–50, –40] and [40, 50)	0	0.00	0	0.00	127	2.8
(–70, –50] and [50, 70)	0	0.00	43	0.96	71	1.6
(–90, –70] and [70, 90)	0	0.00	17	0.37	20	0.4

5. Summary

The results of test surveying showed very high precision in determining the position of the points regardless of the type of the selected network data in the RTCM 3.1 format of the NAWGEO service. For the horizontal coordinates, most of the results were comprised in the range of ±1 cm (98%), however, for the heights, 90.6% of the solutions were comprised in the same range.

In the case of testing the accuracy of determining the coordinates, the results are not equally good. However, they meet the criterion provided on the ASG-EUPOS website on the accuracy of horizontal coordinates at the level of ±3 cm and a height of ±5 cm in 98%. An important observation from the analysis of the surveying results is the possibility of obtaining systematic errors of the value of a few centimetres. They emerged occasionally, however, the user would have received in these cases solutions of high precision, which would not have given rise to any major concerns. These surveys will be analysed in detail in order to determine the reasons for the calculation of coordinates with such large errors. Currently, at least in the measured area, there were continuous problems with the availability of data from the ASG-EUPOS network, as mentioned in clause 3.

As of today, the ASG-EUPOS network provides data free of charge. The use of real-time services typically requires the use of the GPRS data transmission packet. The cost of calls depends on the operator and the selected tariff. During the tests a pre-paid card of one of the operators was used. The RTN measurement cost on particular days amounted to about 5 zloties. It resulted from the established testing technology and the performance of subsequent surveys based on different types of data, which resulted in each time interrupting a GPRS connection and establishing a new one.

The RTN measurements using ASG-EUPOS network is the fastest method of conducting satellite surveying. The users have to, however, define the scope of their applications due to the accuracy of the survey results in terms of the requirements of the issue which the user wants to achieve. The calculation must also take into account frequent interruptions in the possibility of use of the EUPOS ASG data as well as the risk of lack of coverage of GPRS service in GSM network.

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