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RTN Measurements Accuracy Test in Reference to MSPP**

1. Introduction

In the recent years, the Real Time Kinematic measurements (RTK) have evolved to the Real Time Networks (RTN) surveys, consisting in the replacement of the real reference station data stream with the calculated area corrections parameters and/or the virtual station [3].

In Poland, the terrestrial navigation system for position determination – Active Geodetic Network European Position Determination System (ASG-EUPOS) [8] was made available to the users in June 2008. This system is the Polish part of the European system covering 15 countries of the Central and Eastern Europe. The ASG-EUPOS network in Poland was preceded by the Active Geodetic Network (ASG-PL), the regional project launched on 25th of February 2003 by GUGiK and the Silesia Province Authorities. The ASG-PL website was closed on 18th of October 2008 and it was the last stage of this network incorporation in the ASG-EUPOS system. The resolution of the Małopolska Province dated at 23rd of January 2006 on "the construction of the Małopolska Regional System for Precision Positioning having the general economic purpose for the Małopolska Province" has created grounds for the actions which resulted in creating, in September 2006, the Małopolska System for Precise Positioning (MSPP) [9], to which the ASG-PL network was connected, and added the real-time correction generating module at the same time. The MSPP operates currently in parallel with the ASG-EUPOS, and its reference stations have been connected to the ASG-EUPOS. Both, the ASG-EUPOS and MSPP systems use software from the same supplier.

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The paper presents results of the test points measurements in relation to the reference stations of the Małopolska System for Precise Positioning. They provide practical verification of the information available through the MSPP website on the accuracy of positioning, at least 3 cm in horizontal and 5 cm in vertical, at 99.9% level of confidence. The results are based on the measurements of the 24 test points.

2. Project and Calculation the Reference Coordinates for the Test Points

The test points locations have been arranged in such a manner that they are located in 3 different directions from the KRAW station in Krakow. As shown in figure 1, the KRAW station is located centrally on the area of the MSPP coverage. Points in a given direction were stabilised in 3 groups of 3 points each. Points in a given group were stabilised in the distances from several to 100 m, maintaining sighting line between them. Groups of points in a given direction were stabilised in relation to the KRAW station in the distances of ca. 12, 21 and 34 km. Distances 12 and 34 km were selected based on the RTK single baseline correct solution and maximum distance from the reference station of the ASG-EUPOS system designed. 60 mm long stainless steel bolts were used as the measuring signs for all the 27 points. The stabilisation involved pouring epoxy resin into a drilled hole and placing a measuring sign inside. The group of points in Olkusz appeared to be inaccessible for the measurements.

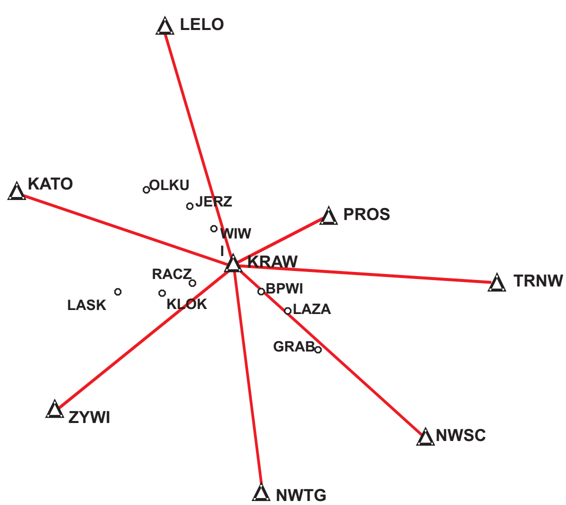

Fig. 1. Map of test points and MSPP reference stations

Static GPS surveys, tachymetric measurements, precise levelling and RTN measurements were performed for the test points. Reference coordinates of the test points for the RTN measurements were set based on the static GPS measurements, whose measuring session lasted from min. 6 to 11 hours, and were carried out with simultaneous use of 9 Leica receivers: 2 SR399E receivers, 3 SR530 receivers and 4 GX1230 receivers.

Centring was performed with the aid of precision optical plummets. For the tachymetric measurements, the precision total station TCA2003 was used. The measurement was performed in 3 series. Precision levelling was performed with the DNA03 level. Classical terrestrial measurements allowed, to some extent, to verify the quality of the satellite measurements, and to form the grounds for testing the stability of the locations of test points.

3. RTN Measurements of the Test Points

The RTN measurements were carried out with the SR350 receivers. Such model had to be adapted to the RTN measurements, since its is not equipped with a GSM modem, has no Ntrip client [7] implemented in its firmware, and has neither an USB port nor bluetooth module. The technical solution adopted for the test measurements was chosen based on the results of tests which indicated more stable connection with the MSPP caster via the GNSS Internet Radio application, than via java applications for a cellular phone connected to a GPS receiver. For that reason, in the RTN measurement a laptop with the GNSS Internet Radio application installed was used. Although the GPS receiver antenna during the tests was placed on a stand, a solution was sought that could operate in the portable mode, i.e. sustaining the mobility of a GPS receiver. Hence, a bluetooth module was connected to the laptop, via the USB port, in order to allow wireless communication between the computer and GPS receiver without compromising its mobility. The bluetooth module ensured communication between the devices according to its class, within a 100-metre range. Connected to the computer, the bluetooth module was also intended to maintain communication with the cellular phone. The latter allowed communication of the GNSS Internet Radio application with the MSPP caster through the GPRS protocol. The GPS receiver communicated with the laptop using the bluetooth module connected to the GPS receiver through the RS232 serial interface.

A simpler solution that would allow the SR530 receiver to perform the RTN measurements is to use a cellular phone with the Ntrip client application, e.g. mobilneNtrip. Direct communication of the cellular phone with the GPS receiver in the SR530 model can be provided only through a cable interface via the RS232 port.

Currently, the GPS receivers have the Ntrip protocol client implemented in their software. The GSM modem is integrated with the GPS receiver or connected with a wireless link.

The RTN measurements were made for each of the 24 points, for the mountpoints presented in table 1, in series of minimum 30 point positions for each mountpoint (stream of data generated by a reference station). During the measurements, almost 3000 positions of the test points were determined. The GPS antenna was placed on a stand, and the centring was performed with a precision optical plummet.

Table 1. Mountpoints used for the test measurements

Mountpoint	Format	NMEA
RTCM_FKP	RTCM_SAPOS	Yes
RTCM23_VRS	RTCM 2.3	Yes
RTK30	RTCM3Net	Yes
KRAW_RTCM30	RTCM 3	No

4. Assessment of the Quality of the Test Points Reference Coordinates

The basic issue while assessing the determination accuracy of points position in the RTN measurements in reference to the MSPP, was to determine, possibly most precisely, the coordinates of the test points based on the static GPS measurements. Such coordinates were compared with those obtained from the RTN measurements. Calculations for the GPS, tachymetric and levelling measurements were performed with the aid of Leica Geo Office v. 7.0 [1]. Normal heights of the points were determined based on the Geoida 2001 model.

The quality of the static measurements and of the coordinates calculated accordingly, was evaluated based on the analysis of post-processing results and equalisation of the GPS vectors, comparison of the GPS vector lengths and measurement results with the TCA2003 tachymeter, comparison of the height differences and results of precision levelling.

Based on the results of the GPS vector adjustment obtained in the static GPS measurements, selected values characterising the quality of tests points positions are given in table 2: coordinate standard deviations (Sd), coordinate quality (Qlty), semi-axes of error ellipses and external reliability of the coordinates (Rel.) in the east-west and north-south orientation.

Quality of the 2D position, height and 3D position was calculated from the equations:

$$2D.Qlty = M_0 \cdot \sqrt{Q_{11} + Q_{22}} \tag{1}$$

$$H.Qlty = M_0 \cdot \sqrt{Q_{33}} \tag{2}$$

$$3D.Qlty = M_0 \cdot \sqrt{Q_{11} + Q_{22} + Q_{33}} \tag{3}$$

The external reliability can be defined as the largest effect of an undetected error in observations on a coordinate component [2, 6].

Table 2. Selected parameters characterising the quality of reference coordinates of the test points

Statistic	Sd. East.	Sd. North.	Sd. Height	2D.Qlty	H.Qlty	3D.Qlty	Semi-major	Semi-minor	Rel. E-W	Rel. N-S	Rel. H
Max	0.002	0.003	0.005	0.003	0.005	0.006	0.003	0.002	0.003	0.003	0.004
Min	0.001	0.001	0.002	0.002	0.002	0.003	0.001	0.001	–0.003	–0.003	–0.004
Sd.	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000	0.002	0.002	0.002
Mean	0.001	0.002	0.003	0.002	0.003	0.004	0.002	0.001	0.000	0.000	0.000

The analysis uses also the results of classical terrestrial measurements which can be regarded practically correct for the GPS measurements. This is, among others, indicated by the errors of equalised coordinates of test points calculated by the terrestrial measurements, not exceeding 1 mm.

After reduction to the level, the lengths of post-processing GPS vectors and corresponding distances from TCA2003 measurements were compared. For most of the pairs being compared, the differences did not exceed 5 mm, and for 9 of 24 vectors (38% of vectors) did not exceed 1 mm! The greatest differences of 19 mm, were found for the WIWI01-WIWI03 and WIWI01-WIWI02 vectors. It has to be stressed here that the values were analysed prior to the adjustment. Furthermore, the influence of the MSPP quality on the results of the satellite measurements was not taken into consideration. It was assumed that the user would simply use the services provided by the MSPP. From the satellite measurements, the ellipsoidal heights were determined. Based on the levelling geoid model of 2001, the normal heights were determined for the test points. Height differences between points in a group was calculated based on the precision levelling.

The comparison included the following:

– differences of ellipsoidal heights to the differences of normal heights which did not exceed 5 mm, for 13 height differences (54% of height differences) they did not exceed 1 mm,
– differences of ellipsoidal heights to the levelling height differences,
– differences of normal heights to the levelling height differences.

The values calculated differed slightly for both, the comparisons of ellipsoidal heights and differences of the normal heights to the levelling height differences. In both cases, the differences did not exceed 6 mm and for 7 height differences (38% of value pairs being compared) they did not exceed 1 mm. The exception is the GRAB group of points for which the differences, in case of the ellipsoidal heights, were 16 mm, 17 mm, 32 mm and 14 mm, 16 mm, 29 mm for the normal heights.

Analysis of the measurement results allows the conclusion that the coordinates determined for the test points, based on the static satellite measurements, can be accepted as sufficiently accurate and be used as the reference coordinates for comparisons with those of the RTN measurements.

5. Analysing the RTN Measurement Results

Coordinates for each test point were determined min. 30 times for the mountpoints: RTCM_FKP, RTCM_23VRS, RTK3.0 (RTCM 3.0 VRS) and KRAW_RTCM30 (Single Baseline solution).

In figures 2 to 5, the differences of reference coordinates of the test points from the static GPS measurements (STS) and coordinates of those points from the RTN for the above mountpoints are presented.

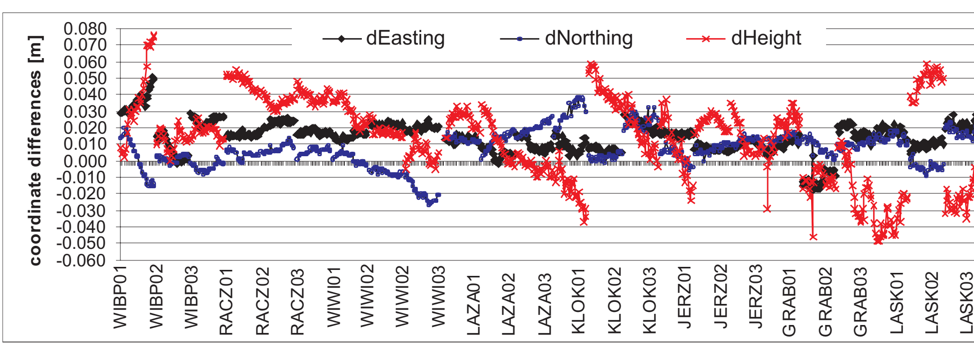

Fig. 2. Coordinate differences of STS-RTN test point – mountpoint RTCM_FKP

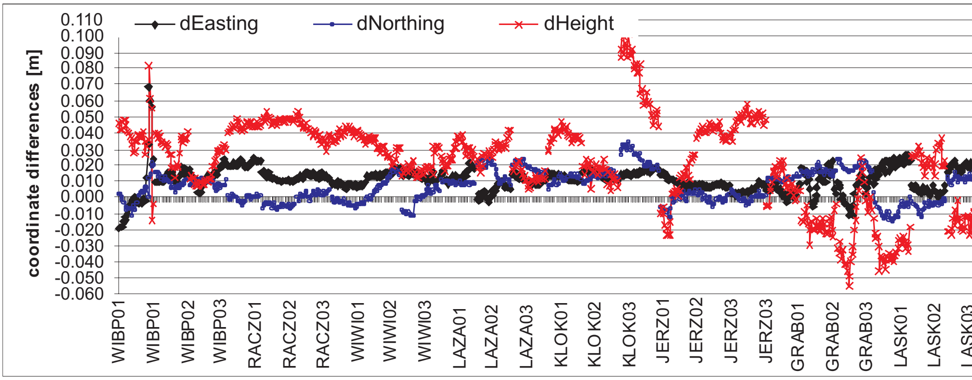

Fig. 3. Coordinate differences of STS-RTN test point – mountpoint RTCM_23VRS

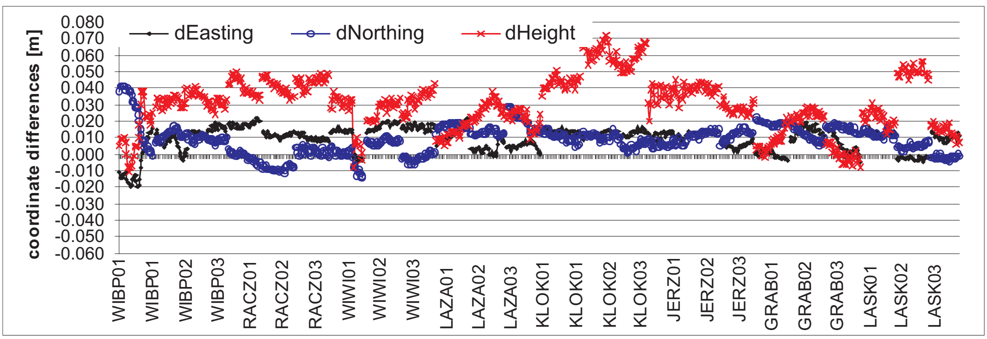

Fig. 4. Coordinate differences of STS-RTN test point – mountpoint RTK3.0

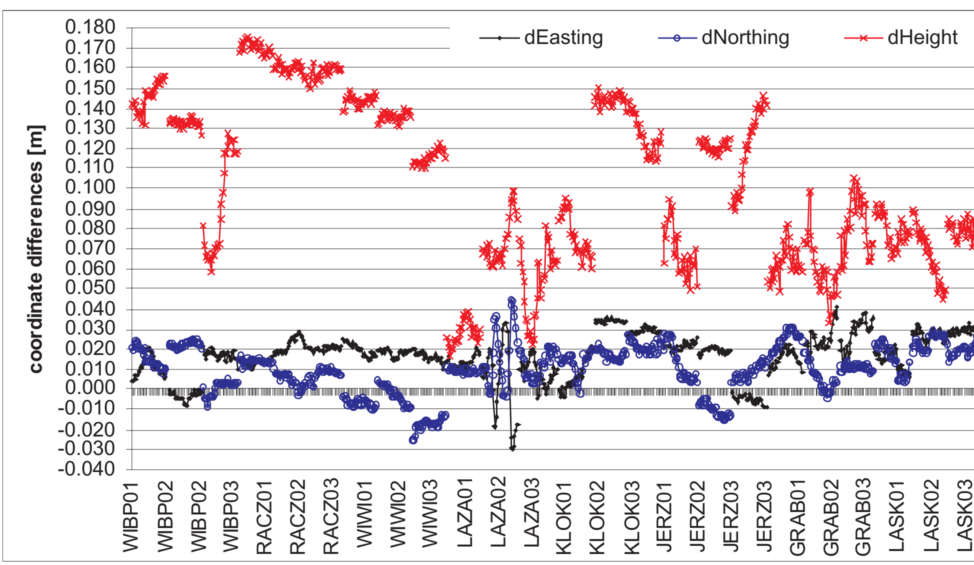

Fig. 5. Coordinate differences of STS-RTN test point – mountpoint KRAW_RTCM30

Groups of points were sorted according to the distance from the KRAW station, from the nearest to the furthest stabilised ones. Great height differences for the KRAW real reference station (Fig. 5), even up to 17.6 cm, are most visible. The KRAW reference station is provided with the ASH701945B_M SNOW antenna of eccentric values: L1 = 10.93 cm, L2 = 12.62 cm.

An assumption that the differences are caused by the failure to consider the antenna eccentric while determining the height of the reference point would give good results. However, in case of the LAZA01 point, the height differences did not exceed 4 cm. Attention should also be drawn to the fact that in case of the KRAW_RTCM30 mountpoint, almost all the STS-RTN horizontal coordinates differences were within the limit of ±3 cm, for vector lengths of approx. 12 km, 21 km and 34 km.

Table 3. Positioning precision analysis in reference to MSPP

Mount point	RTCM_FKP			RTCM_23VRS			RTCM 3.0 VRS			KRAW_RTCM30		
Coord.	East.	North.	El.Hgt.	East.	North.	El.Hgt.	East.	North.	El.Hgt.	East.	North.	El.Hgt.
Max	0.015	0.018	0.038	0.065	0.020	0.044	0.023	0.018	0.413	0.029	0.028	0.078
Min	–0.009	–0.017	–0.047	–0.022	–0.012	–0.052	–0.015	–0.025	–0.031	–0.034	–0.030	–0.034
Mean sd.	0.003	0.003	0.008	0.004	0.003	0.007	0.003	0.003	0.008	0.004	0.004	0.009

Table 3 presents results of the positioning precision analysis for the MSPP. The parameter which describes the precision may be the standard deviation, the average values of which are given in table 3. Such values do not exceed 1 cm. Table 3 presents also the minimum and maximum values of coordinate differences of individual measurements of a each mountpoint in relation to the average values of such coordinates.

6. Conclusion

The test procedure of positioning accuracy of points in reference to MSPP, the coordinates of points, derived from the RTN measurements were compared with the coordinates of points from the static GPS measurements (STS). Reference coordinates of the test points were not error-free, however, based on the measurements with the TCA2003 precision tachymeter and with the precision DNA03 level, their values were verified. The accuracy of reference coordinate setting for the test points was: 3 mm horizontal and 6 mm for height. Since the difference of the STS-RTN coordinates reached the values in centimetres in case of the situation, and decimetres for the height, it was concluded that the accuracy analysis can be performed for the determination of point coordinates in relation to the MSPP.

While analysing the averaged results of the measurements of the test points, it can be concluded that the information published on the MSPP website (regarding the point position accuracy of at least 3 cm horizontal and 5 cm for height) is reflected in the measurement results. Considering each of the solutions individually, such values happened to be exceeded for the horizontal coordinates (3.6%), whereby they occurred most frequently in the Single Baseline for the KRAW_RTCM30 mountpoint. However, the lengths of vectors in the case in question exceeded the indicative limit for the correct Single Baseline solution which is 10 km. Positions of points for vector lengths of ca. 12 km, 21 km and even 34 km were determined. For the heights, the greatest differences, of decimetres, were present in case of the Single Baseline mountpoint (Fig. 5). For numerous measurements, also the "solution flowing" phenomenon was discovered for all types of mountpoints (real reference station, area correction parameters (FKP), virtual referential station) consisting in increasing or decreasing the coordinate values in repeated measurement of a point. The occurrence of the systematic factor in the measurements is typical. Coordinate differences in most cases have the positive values.

Similar tests will also be preformed for the ASG-EUPOS system. Attention should also be drawn to the fact that the coordinates of the same physical reference stations in the MSPP and ASG-EUPOS differ in both systems.

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