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Verification of applicability of the Trimble RTX satellite technology with xFill function in establishing surveying control networks

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Abstract: The paper presents the results of real time measurements of test geodetic control network points using the RTK GPS and RTX Extended technologies. The Trimble RTX technology uses the xFill function, which enables real measurements without the need for constant connection with the ASG EUPOS system reference stations network. Comparative analyses of the results of measurements using the methods were performed and they were compared with the test control network data assumed to be error-free. Although the Trimble RTX technology is an innovative measurement method which is rarely used now, the possibilities it provides in surveying works, including building geodetic control networks, are satisfactory and it will certainly contribute to improving the organisation of surveying works.

Keywords: RTK GPS, RTX, Trimble xFill, geodetic control network

1. Introduction

In recent years, many scientists directed their research towards definition of a new (improved) Precise Point Positioning technique (PPP), as an alternative to RTK (Real Time Kinematic) based on permanent reference stations. The result of these activities was development of a new product on the surveying market, i.e. the RTX technology (Real Time eXtended). It is relies on the OmniSTAR system, which employs a constellation of telecommunication satellites and is based on a network of reference stations, located on different continents and using innovative algorithms for defining corrections for GNSS receivers (www.geoforum.pl, 2013).

Most RTK systems are currently receiving corrections from a reference station by radio or by mobile phone (via the Internet). The reference station in this case may be a single physical base station or a VRS (Virtual Station), data for which are generated by a network of receivers. Although the reference stations may be 40 to 70 kilometres apart, the VRS data are interpolated for a virtual, fixed position near the rover. Figure 1 illustrates the two types of streams of RTK corrections (White Paper, 2012).

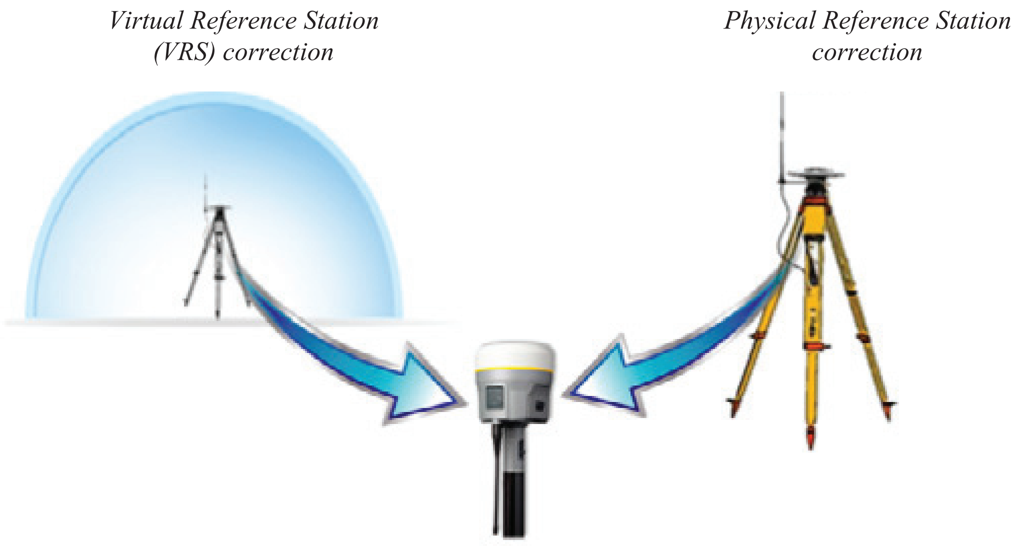

Fig. 1. Possible sources of corrections for most RTK systems: single physical reference station or VRS (White Paper, 2012)

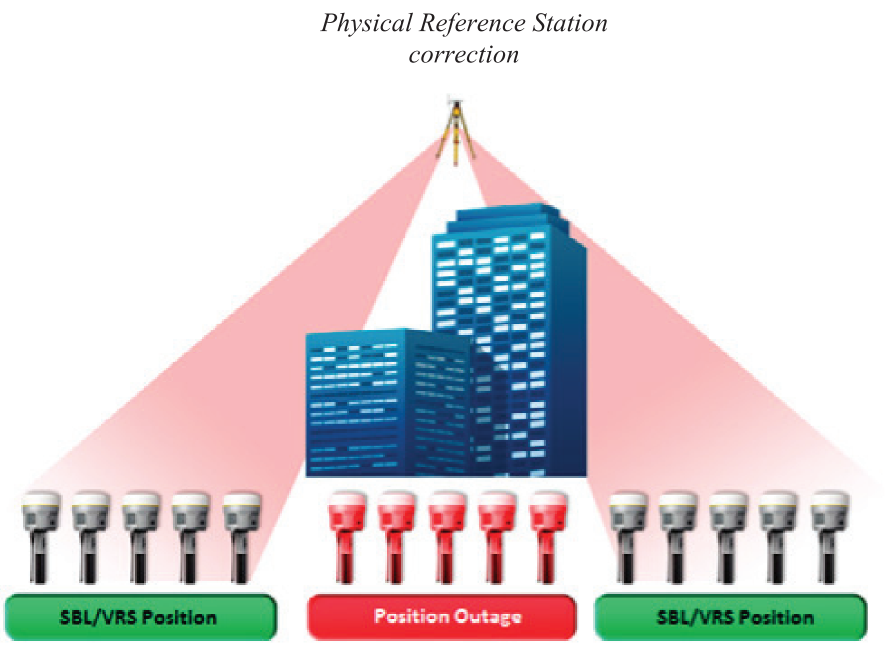

Fig. 2 RTK solution outage caused by a building obscuring the RTK radio signal (White Paper, 2012)

The Trimble RTX with xFill function is a technology that supports the standard RTK systems in case of outages of corrections from their primary source: a physical reference station or a stream of VRS data.

A typical case of radio failure is shown in Figure 2, which illustrates loss of radio signal caused by buildings. Signal fading takes place in areas, where a building is located between the user and the reference station, effectively blocking the signal and causing the suspension of RTK positioning.

In the areas with satellite signal coverage the system Trimble RTX with the xFill function determines position either with the data from a single base station or with data from a VRS station, as long as they are available, or the RTX data stream. In case of interruption of the reference signal (Fig. 2), the Trimble RTX system with the xFill function provides a mechanism for maintaining high precision RTK positioning based solely on GNSS observations collected by the rover. Using the RTX data, the moving receiver "fills the gap" caused by the break of the original correction streams – hence the name of the function xFill, see Figure 3 (White Paper, 2012).

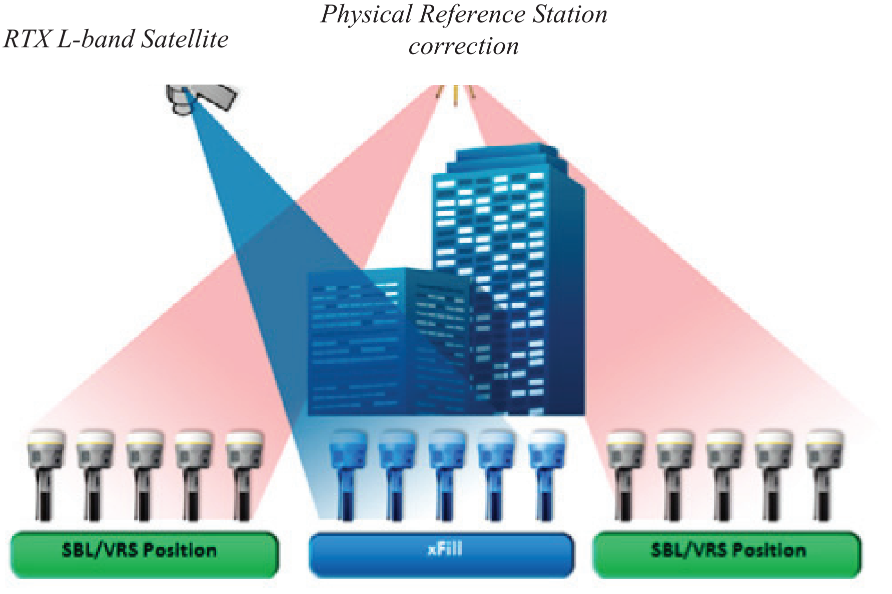

Fig. 3. Expected behavior of the rover using the Trimble functions xFill (White Paper, 2012)

In result, when it comes to loss of corrections from reference stations, the Trimble RTX data streams, transmitted by an independent link (RTX L – satellite band) instead of the base station radio or GPRS, are usually available. The terrestrial radio signals are sometimes blocked, though a good view of sufficient number of GNSS satellites and access to the RTX data stream are still maintained. Under such circumstances the rover furnished with the xFill function is consistently able to deliver positions like in the RTK mode (White Paper, 2012).

The new technology is provided by the *RTX^{TM} centerpoint* positioning service, which allows positioning with the accuracy at the level of single centimetres all over the world in real time, without direct use of reference stations infrastructure. However, the main drawback of this technique is its relatively long convergence time required to achieve positioning with such accuracy. The convergence time is typically several dozen of minutes, but sometimes it may take up to several hours, depending on the geometry of satellite constellation, and weather conditions (Leonardo et al., 2011).

The RTX system operates on the basis of precise satellite information, generated in data processing centres, as shown in Fig. 4.

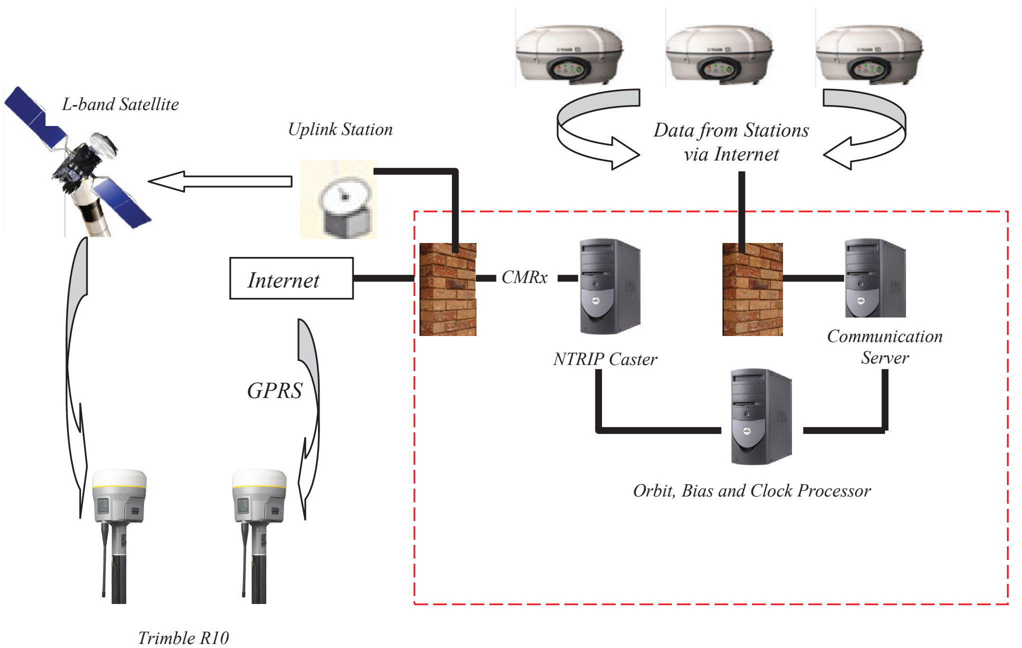

Fig. 4. RTX technology system infrastructure overview

Data from monitoring stations located around the world are collected and transmitted via the Internet to working centres located in various places. They are also called operating centres (dashed red line in Figure 1), within which the reserve communication servers are used for processing and transferring data, such as precise parameters of satellite orbits, satellite clocks corrections and predictability of observation. Then, accurate satellite data are compressed in accordance with the CMRx message format. In the final stage, the messages are sent to uplink stations or made available to users through the Internet (Leonardo et al., 2011).

Requirements for satellite orbits used in the global RTX system consist primarily of accuracy, continuity, solidity and reliability. Satellite positions should be accurate, but due to the fact, that real-time positions are computed using double differences of phases, orbit have negligible impact on the determined rover positions. The requirement of continuity is introduced to avoid the necessity of modelling observation inconsistencies in time. RTX network processors use a variety of techniques to control data in order to ensure their highest quality, when used for calculation of the final products. Furthermore, reliability is a very important factor for real time data processing. Currently orbit processors are able to work for several months with no intervention from operators while processing various events (Leonardo et al., 2011).

Determination of precise orbit parameters in the RTX^{TM} centerpoint system is based on a combination of the Kalman filter for estimating the satellites position and velocity, conditions of troposphere, the ambiguity resolution of phase measurements, solar radiation pressure parameters, harmonic coefficients of Earth gravity field and Earth orientation parameters. In this process, the problem of determination of integer phase ambiguities is resolved in real time. This means, that rover positions determined with help of the reference data, with basic systematic errors filtered out thanks to the difference technique, after loss of the data link can still be determined with satisfactory accuracy, though for several minutes only.

Estimation of the satellite clock errors is the fundamental part of the RTX system, which plays a vital role in positioning efficiency. The speed of clock data processing is important due to the fact, that assessment of clock errors is intimately related to the ambiguity resolution, so any delay in computation of these errors has direct impact on position determination. The architecture of the clock processor is based on an innovative design, that allows simultaneous processing of data from hundreds of the system reference stations. The aim is to make the time of processing of such data as short as much as possible, in order to facilitate 1 Hz positioning.

Effective approach to estimate clock errors has been presented by (Zhang et al. (2011). It concerned a combined use of dual-thread algorithm consisting of undifferenced (UD) and epoch-differenced (ED) engine. The UD engine produces absolute clock values every 5 seconds, and the ED engine produces relative clock values between neighboring epochs in one – second interval. In the final effect, frequency of 1 Hz satellite clock can be obtained by combining the UD absolute clock values and the ED relative ones.

As mentioned before, one of the features of the RTX system is observation predictability, which, when properly modelled, allow to achieve complete and accurate (to several centimetres) observations in GNSS. The main objective of generating such observations is to preserve the continuity requirement, which is introduced in order to avoid the possibility of inconsistent modeling at the time of observation.

During designing RTX system communications, a new message format was created to transfer information on satellite orbits, clocks, observation predictability and other auxiliary information. The new format was based on earlier concepts developed by Trimble as part of the CMRx RTK format (Leonardo et al., 2011).

Positioning in the RTX technique has several technical aspects borrowed from the previously existing RTK Trimble technique. This enables the RTX positioning mode to easily coexist with the traditional RTK modes. As far as the efficiency of positioning is concerned, RTX performs typical positioning with accuracy to 1-2 cm horizontally and 2-4 cm vertically. Final convergence of the system is achieved in 10 to 45 minutes from the start of the rover.

Convergence time may depend on various factors, including the geometry of the satellite constellation or multipath properties of signals. In order to reduce convergence time in RTX positioning a range of functions are used. One of them is the so-called quick restart, which allows users, who have not made changes to their position from the last RTX solution, to immediately obtain a converged solution. The second feature is related to the avoidance of re-convergence system. This feature protects the system from entering a new phase of convergence in the case when the receiver loses connection to the satellites for a period of up to a few minutes, e.g. when working behind a line of trees or under a bridge (Leonardo et al., 2011).

Subsequent proposal aiming at reducing the convergence time is to use two satellite systems GPS and GLONASS in the real-time measurements. A number of studies have shown that the solution of this type accelerates obtaining a convergent solution in comparison to works based on GPS only. Average time for the convergence of the system using GPS and GLONASS can be reduced by 42% (Zhang et al., 2013).

The RTX technology allows the use of the Trimble xFill[1] function, which allows to continue surveying, even if the primary RTK or VRS correction stream is not available. This is made possible by providing access to the technology around the world by satellite broadband connections. The Trimble xFill function provides the possibility to use new and innovative techniques for RTK measurements (www.3dcad.pl, 2013). In the case of broken communication with the primary source of RTK or VRS corrections, the GPS receiver automatically switches to the RTX measuring mode with the Trimble xFill function. Theoretically (manufacturer's data) working time in this mode may not exceed five minutes. The new way of data processing is different, competitive for the traditional solutions of the fixed/float phase ambiguity. It features uncertainty weighting, which allows for better error estimation compared to conventional GNSS solutions.

Surveying, including establishing of the surveying control network using the RTK GPS technology, is currently regulated by the Ministry of the Interior's and Administration Regulation of 9th November 2011 *in case of technical standards of performing detailed surveys and working out and sending results of these surveys to National Geodetic and Cartographic Store*. Nevertheless, this regulation and other previous guidelines do not regulate many other aspects related to real time measurements, or obligate to perform actions which do not always have to be done in accordance with the regulation to achieve the required accuracy. Due to the lack of clear legislation regulating the new measurement technology, i.e. RTX, the basic objective of the study was to analyse the results of measurements performed

[1] Trimble xFill – a new service which continues RTK positioning for a few minutes when the RTK correction stream is not available. Trimble Xfill corrections are transmitted by satellites, so they are generally available within the areas covered by the GNSS constellation (White Paper, 2012).

using the RTX technology with the Trible xFill function in relation to the legally regulated RTK GPS technology. RTK GPS technology is one of the methods, that can be used to establish the surveying control network satisfying the requirements of the regulation (MIA, 2011). Confirmation of relatively high accuracy of RTK GPS method in the context of establishing surveying control networks, based not only on the above mentioned regulation can be found in researches by (Krzyżek, et al., 2012). Basing on the similarities of the RTK and RTX methods, the study also attempted to find a link between the methods in the context of their mutual use to build the surveying control network. The results may partly serve to moderate optimisation of measurement factors for the implementation of the surveying control networks using GNSS systems.

2. Research experiment

The test ground was located in the area of Jerzmanowie-Przeginia Commune in vicinnity of Kraków, on an area of approximately 200 hectares. The study used a fragment of an existing control network of the class III (marked in accordance with the standard G-1), established and adjusted in 2005 (Fig. 5), documented in PODGiK (Provincial Geodetic and Cartographic Documentation Centre) in Krakow.

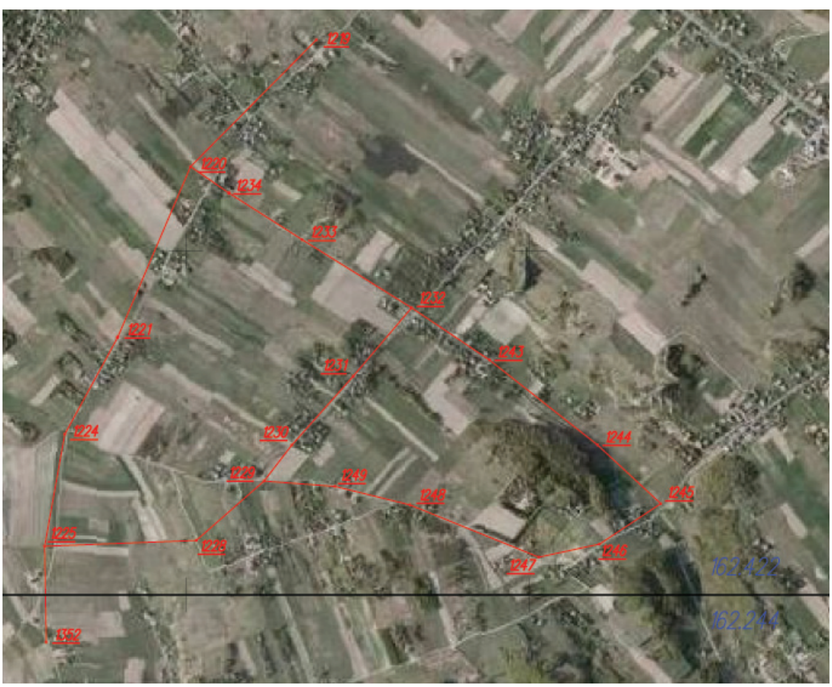

Fig. 5. Sketch of a fragment of the 3rd class detailed control network (test network) in “Jerzmanowice-Przeginia” area

The documentation shows, that the average error of adjusted point positions of the tested geodetic control network did not exceed ±0.003 m for horizontal coordinates and ±0.005 m for the vertical coordinate. Due to such high point position precision of the control network, coordinates of these points were taken as reference points – catalogue coordinates for further comparative analysis, and marked ”3rd class CAT.” in further determinations of coordinates. It should be noted, that coordinates of the reference points are not considered errorless, despite their low average error. The assumption of their values as a reference level to other research results is used in the context of comparison of the RTK or RTX surveyed positions to said data. The RTK and RTX methods achieve positioning accuracy on the level of several centimetres, so are substantially less accurate than the accepted reference ”catalogue” coordinates.

Trimble GNSS R10 receiver was used for real-time measurement of test points. The measurements were performed using the ASG EUPOS system and the NAWGEO_VRS_2_3 service.

The system of permanent reference stations ASG-EUPOS-PL was put in operation in Poland in the year 2008. Its main features, technical details and services of data distribution are given in the paper *Technical details of establishing reference station network ASG-EUPOS* (Wajda et al., 2008). ASG EUPOS system with the use of NAWGEO service assures accuracy of measurements in real time not worse than 3 cm for horizontal coordinates and less than 5 cm for heights with the confidence level of 99.9% (www.asgeupos.pl, 2013). Verification of this assumption was carried out and confirmed by (Uznański, 2010). Other researches carried out in the real time using virtual reference stations (VRS) allow obtaining even better results than those mentioned above (Hu et al., 2003). Shortly after the launch of ASG EUPOS system tests on enhancing efficiency of the real-time services have been started. To this end a number of researches for the so-called ASG+ project have been done, which will support a number of modules for real-time measurements (Figurski et al., 2011).

Several scientific and technical papers, pertaining to the operational aspects of the system, were published in the last few years.

The location of the test area with respect to the nearest ASG-EUPOS stations is shown on the Fig. 6.

Each test point was measured sequentially by two methods: RTK GPS and Trimble RTX using xFill function. When surveying with the RTK GPS technique, the measurement mode was set to average the final result from 30 epochs. On the other hand, when using the RTX Trimble technology, the time interval in the measurements ranged from a few to a dozen or so seconds (most often 8 – 10 seconds), and was triggered by the observer. During measurements of points using the RTX with xFill technology, the possibility to continue measurements in time range given in the manufacturer’s data, was verified. In both methods the SurePoint technology was used, thanks to which the range pole deflection was constantly monitored, what prevented recording erroneous data and allowed recording only the data for which the pole was positioned vertically. The maximum allowed range pole deflection was set in the receiver options to ±0.010 m, while the allowed error of horizontal point position was set also to ±0.10 m, and the vertical position error to ±0.05 m. When any of these thresholds was exceeded during the measurements, positioning was interrupted and further work was impossible.

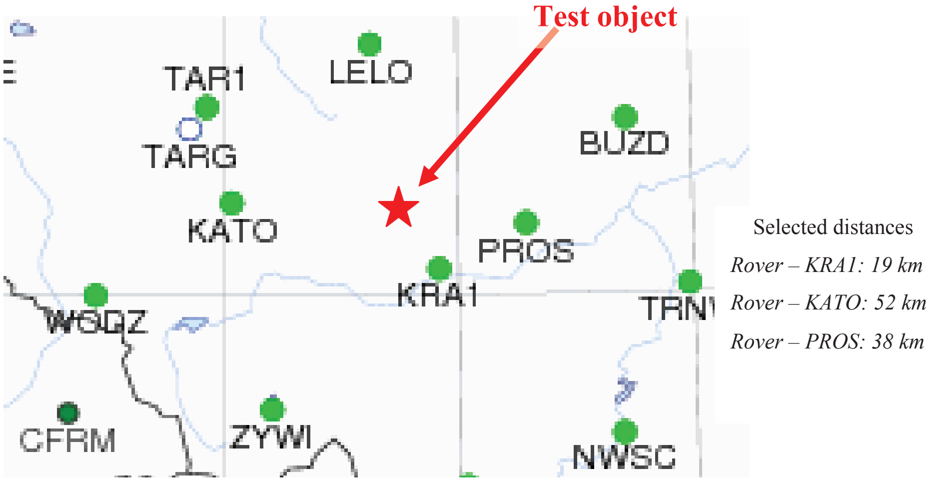

Fig. 6. Arrangement of permanent stations ASG-EUPOS nearby municipalities Jerzmanowie-Przeginia test (www.cgs.wat.edu.pl, 2013)

As a result of the research experiment, orthogonal coordinates X, Y, H in the *PL 2000* national system were determined for each measurement technology, and a comparison was made. First, coordinates X, Y, H determined with the three methods were compared in pairs (RTK-RTX, RTK- 3rd class CAT., RTX-3rd class CAT.), what in result gave deviations dX, dY and dH for every coordinate of the test points (Table 1). Point number 1243 was excluded due to its significant damage. Point number 1244 was totally excluded from the study due to the lack of measurement possibility using RTK and RTX, i.e. complete horizon obstruction from the south by a forested hill (Fig. 2). A *null hypothesis* was formulated for the obtained coordinate deviations, which reads: *the average value of μ for coordinate difference deviations (dX, dY and dH) in individual pairs of methods (RTK-RTX; RTK- 3rd class CAT. and RTX – 3rd class CAT.) is equal to the set value* $\mu_0 = 0$.

$$H_0 : \mu = \mu_0 \tag{1}$$

For the *null hypothesis* an *alternative hypothesis* was defined, which reads: *the average value of μ for coordinate difference deviations (dX, dY and dH) in individual pairs of methods (RTK-RTX; RTK- 3rd class CAT. and RTX – 3rd class CAT.) does not equal the set value* $\mu_0 \neq 0$.

$$H_1 : \mu \neq \mu_0 \tag{2}$$

Table. 1. Coordinates X, Y, H deviations between individual measurement technologies.

Point no.	RTK-RTX [m]			RTK-3rd class CAT. [m]			RTX-3rd class CAT. [m]		
	dX	dY	dH	dX	dY	dH	dX	dY	dH
1220	-0.015	-0.001	-0.056	0.022	0.012	0.039	0.037	0.013	0.095
1234	-0.006	-0.007	0.020	-0.001	-0.037	0.037	0.005	-0.030	0.017
1221	-0.014	0.001	0.003	0.022	-0.013	0.024	0.036	-0.014	0.021
1224	0.003	-0.025	0.013	0.017	-0.036	0.015	0.014	-0.011	0.002
1225	-0.018	-0.001	-0.012	0.060	0.006	0.020	0.078	0.007	0.032
1352	0.001	-0.004	0.007	0.008	-0.065	0.039	0.007	-0.061	0.032
1228	-0.003	-0.001	0.014	0.006	-0.005	-0.026	0.009	-0.004	-0.040
1229	0.003	-0.006	0.001	0.000	-0.012	-0.043	-0.003	-0.006	-0.044
1230	-0.021	-0.016	-0.045	0.039	0.017	0.012	0.060	0.033	0.057
1231	0.012	0.010	0.044	0.027	-0.011	0.044	0.015	-0.021	0.000
1232	-0.006	-0.001	0.000	0.028	0.002	0.061	0.034	0.003	0.061
1233	-0.020	0.010	0.010	0.022	0.020	0.126	0.042	0.010	0.116
1245	0.015	-0.002	-0.001	0.066	-0.050	-0.023	0.051	-0.048	-0.022
1246	0.015	-0.041	-0.032	0.032	-0.050	-0.023	0.017	-0.009	0.009
1247	-0.003	-0.004	-0.029	-0.041	-0.082	0.007	-0.038	-0.078	0.036
1248	0.005	0.004	-0.015	0.081	0.011	0.060	0.076	0.007	0.075
1249	-0.008	0.002	0.001	0.017	0.007	-0.010	0.025	0.005	-0.011
1219	-0.003	0.004	-0.026	0.053	-0.024	0.037	0.056	-0.028	0.063
average value – μ	-0.004	-0.004	-0.006	0.025	-0.017	0.022	0.029	-0.013	0.028
average deviation – δ	0.003	0.003	0.006	0.007	0.007	0.009	0.007	0.007	0.010
test model – T	-1.3513	-1.5051	-1.0293	3.8248	-2.4314	2.3301	4.1742	-1.9823	2.6607
for significance level of 5% quantile k=n-1	17	17	17	17	17	17	17	17	17
critical value of T- Student distribution – t	2.1098	2.1098	2.1098	2.1098	2.1098	2.1098	2.1098	2.1098	2.1098
Hypothesis verification	H_0	H_0	H_0	H_1	H_1	H_1	H_1	H_0	H_1

In order to draw correct conclusions from the hypotheses tests, calculations of the average value μ for coordinate difference deviations (dX, dY and dH) in each individual set of methods were performed. The average value of standard deviation δ was also calculated for the same data using the following formula:

$$\sigma(\mu) = \frac{\hat{\delta}}{\sqrt{n}} \tag{3}$$

where:

$\hat{\delta}$ – standard deviation of the deviations of coordinate differences (dX, dY, dH) in the particular combinations of methods,

n – number of variations of coordinate differences (dX, dY, dH) in particular combinations of methods.

Depending on the test sample (especially its volume), one of the three models of the T test for the average value was used, expressed as follows:

$$T = \frac{\mu - \mu_0}{\sigma(\mu)} \tag{4}$$

For the average level of significance α=5% of k=n-1 degrees of freedom, the variable T has the T-Student distribution. This distribution was used to construct a double-sided critical area, taking into consideration quantile t(α,k).

As a result of such an analysis of the test sample the following conclusions were drawn:

– average μ value for coordinate difference deviation (dX, dY, dH) between RTK and RTX is statistically insignificant, which generates no basis for rejecting the hypothesis H_0,
– average μ value for coordinate difference deviation (dX, dY, dH) between RTK and 3rd class CAT. and RTX and 3rd class CAT. is statistically significant, which generates a basis for rejecting hypothesis H_0 in favour of hypothesis H_1.

The lack of ground to reject the hypothesis H_0 in comparison of the RTK and RTX methods, allows for optimistic views on the possibilities provided by the xFill function in the Trimble RTX technology. Analysing the deviations of coordinates dX and dY one may notice slight differences, ranging from a few to a dozen or so mm (2 points above 20 mm) and slightly higher values for height deviations – from several to several dozen mm. The fact is, however, that basing on such analyses, far-fetched conclusions on the application of RTX (e.g. in establishing surveying control) cannot be drawn. Nevertheless, they render continuation of research in this field justified. Further studies may present full verification of the accuracy of both methods in certain time series (because of large volume of data, this issue will be presented in a separate publication).

Verification of the proposed hypotheses, even though to a limited extent, definitely confirms the known and legally regulated lack of possibility to establish detailed control networks using real time GNSS techniques. Even though for deviations dY (Table 1) in the comparison of the RTX and 3rd class CAT. methods there is no basis for rejecting hypothesis H_0, a slight difference in the *T* test model of a single average value and the *t* of *T-Student* distribution should be noted. Assuming the significance level $\alpha = 10\%$ would lead to rejection of the hypothesis H_0 in favour of the hypothesis H_1.

For the purpose of stronger confirmation of the alternative hypothesis, hence rejecting the hypothesis H_0 in favour of the hypothesis H_1 (in the comparison of the RTX and 3rd class CAT. methods) another comparison was made (Table 2). The table contains comparison of the coordinates X, Y, H only, between the methods for which the following null hypothesis was formulated: *the average value of μ for coordinates (X, Y, H) for the RTX – 3rd class CAT. equals the set value $\mu_0=0$.*

$$H_0 : \mu = \mu_0 \tag{5}$$

For which an *alternative hypothesis* was defined, which reads: *the average value of μ for coordinates (X, Y, H) for the RTX – 3rd class CAT. does not equal the set value $\mu_0 \neq 0$.*

$$H_1 : \mu \neq \mu_0 \tag{6}$$

The average value of μ in the RTX method was determined basing on the number of measurements made at each point. It should be noted, that due to the varied nature of the terrain (open horizon, obscured horizon, buildings) the period of successful measurement after switching to the RTX mode varied for some points, but never reached the time given by the manufacturer, i.e. five minutes. As a result of the variation of the time, the number of measurements made in the RTX mode was not the same at every point. A similar model of T test (model 4) of the single average value was defined and the same level of significance $\alpha=5\%$. was adopted. In this case, for formula 4, the μ value is the average value of coordinates X, Y, H of each point measured using the RTX technology, and μ_0 is the value of coordinates X, Y, H assumed to be error-free. Also in this analysis the T-Student distribution was used to construct a double-sided critical area, taking into consideration quantile $t(\alpha,k)$.

To sum up the results verifying the proposed hypotheses it may be said, that the average value μ for coordinates (X, Y, H) for RTX-3rd class CAT does not equal the set value $\mu_0 \neq 0$, which causes the rejection of the hypothesis H_0 in favour of the hypothesis H_1. This conclusion confirms the dependences stemming from the proposed *alternative hypothesis* for data in Table 1, i.e. between the results obtained from the RTX method and the coordinates assumed to be error-free (3rd class CAT).

Table. 2. Coordinates X, Y, H in individual measurement technologies

Point no.	RTX [m]			no. of measurm. n	average stand. deviation			3rd class CAT. [m]			Test model – T for RTX – 3rd class CAT.			sign. lvl 5%	critical value	*Hypothesis verification RTX – 3rd class CAT.*		
	X	Y	H		X	Y	H	X	Y	H	X	Y	H			*X*	*Y*	*H*
1220	5564039.935	7410826.881	484.746	19	0.003	0.002	0.004	5564039.898	7410826.868	484.651	12.4298	6.5004	23.7165	18	2.1009	H_1	H_1	H_1
1234	5563962.836	7410938.727	478.250	21	0.003	0.002	0.003	5563962.831	7410938.757	478.233	1.5204	-17.4571	5.5967	20	2.0860	H_0	H_1	H_1
1221	5563543.024	7410615.189	484.397	18	0.003	0.002	0.004	5563542.988	7410615.203	484.376	13.3010	-5.8544	5.7161	17	2.1098	H_1	H_1	H_1
1224	5563260.867	7410461.705	478.407	19	0.002	0.002	0.005	5563260.853	7410461.716	478.405	8.0527	-5.8364	0.3629	18	2.1009	H_1	H_1	H_0
1225	5562935.088	7410403.601	480.122	19	0.003	0.002	0.004	5562935.010	7410403.594	480.090	28.1584	3.7985	8.8353	18	2.1009	H_1	H_1	H_1
1352	5562655.489	7410408.624	468.903	16	0.002	0.001	0.003	5562655.482	7410408.685	468.871	3.0506	-47.3312	10.2800	15	2.1314	H_1	H_1	H_1
1228	5562952.623	7410844.921	486.586	15	0.003	0.002	0.004	5562952.614	7410844.925	486.626	3.4540	-1.7461	-8.9872	14	2.1448	H_1	H_0	H_1
1229	5563125.357	7411041.876	486.599	14	0.002	0.002	0.004	5563125.360	7411041.882	486.643	-1.4720	-3.6395	-10.6042	13	2.1604	H_0	H_1	H_1
1230	5563229.651	7411122.286	483.745	14	0.003	0.003	0.005	5563229.591	7411122.253	483.688	20.8499	13.0550	11.4000	13	2.1604	H_1	H_1	H_1
1231	5563430.588	7411301.150	475.406	11	0.003	0.002	0.006	5563430.573	7411301.171	475.406	5.7620	-8.9917	0.0599	10	2.2281	H_1	H_1	H_0
1232	5563629.896	7411470.431	448.260	12	0.003	0.002	0.004	5563629.862	7411470.428	448.199	11.7649	1.4681	15.6712	11	2.2010	H_1	H_0	H_1
1233	5563827.410	7411151.980	462.830	1	1meas.	1meas.	1meas.	5563827.368	7411151.970	462.714				0				
1245	5563061.035	7412196.592	426.861	16	0.002	0.002	0.004	5563060.984	7412196.640	426.883	24.9848	-21.1402	-5.4841	15	2.1314	H_1	H_1	H_1
1246	5562943.075	7412018.231	454.332	11	0.003	0.002	0.003	5562943.058	7412018.240	454.323	5.8740	-4.3033	2.7112	10	2.2281	H_1	H_1	H_1
1247	5562904.953	7411841.824	452.739	19	0.005	0.002	0.005	5562904.991	7411841.902	452.703	-7.2538	-49.9090	7.3184	18	2.1009	H_1	H_1	H_1
1248	5563056.425	7411466.766	476.245	19	0.002	0.002	0.003	5563056.349	7411466.759	476.170	34.4740	3.5328	24.3264	18	2.1009	H_1	H_1	H_1
1249	5563109.938	7411248.798	486.259	12	0.004	0.002	0.004	5563109.913	7411248.793	486.270	5.9829	2.5079	-2.7215	11	2.2010	H_1	H_1	H_1
1219	5564408.993	7411192.826	477.416	17	0.004	0.002	0.005	5564408.937	7411192.854	477.353	14.3165	-11.3926	12.9516	16	2.1199	H_1	H_1	H_1

To better illustrate the results of measurements in comparison between individual methods, calculations of measured frequency of deviations (differences in coordinates) in a set of linear intervals was performed. 18 common 5 mm long ranges for coordinate differences dX, dY, dH were prepared. They are presented below in the form of histograms (Fig. 7-9).

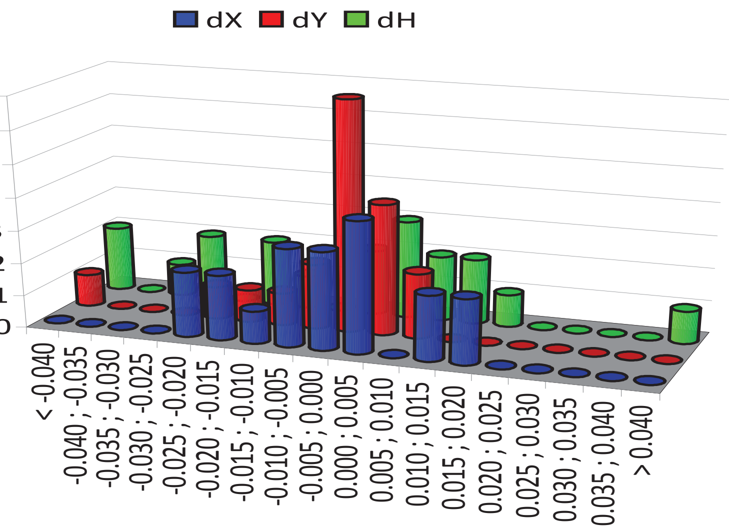

Fig. 7. Histogram of measured frequency for differences in coordinates between RTK-RTX methods

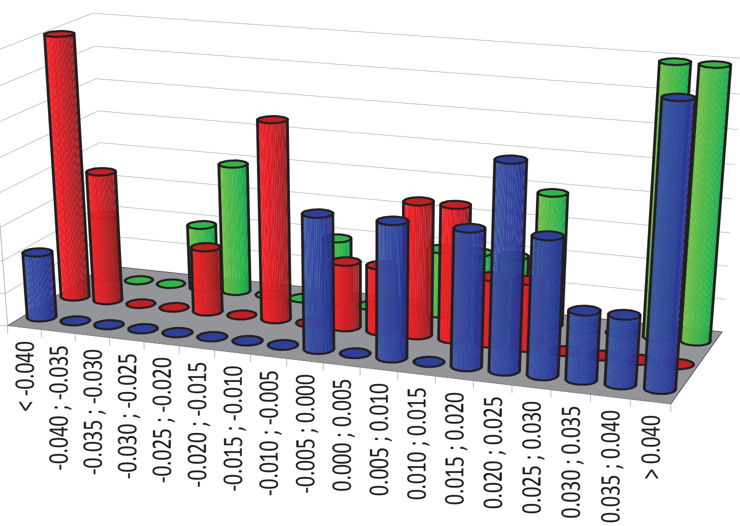

Fig. 8. Histogram of measured frequency for differences in coordinates between RTK-3rd class CAT. methods

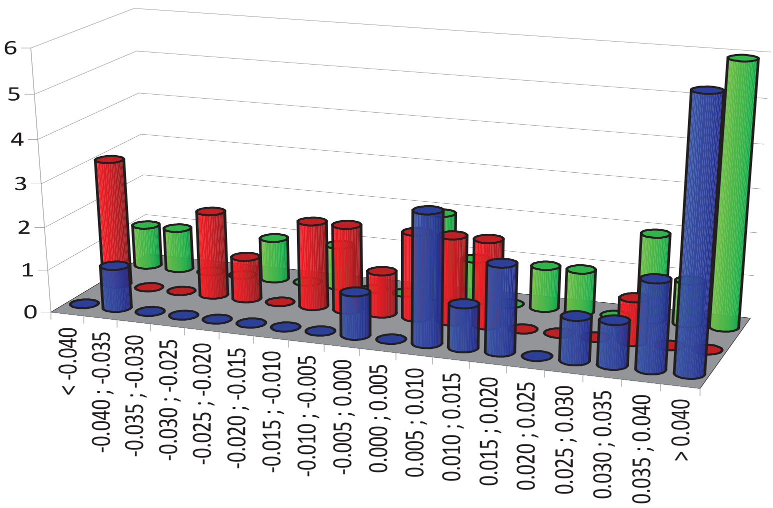

Fig. 9. Histogram of measured frequency for differences in coordinates between RTX-3rd class CAT. methods

The above histograms clearly show the lack of normal distribution for the test sample, which confirms that *T-Student* distribution should be used in the analysis. The only coherence of the measurement results (in relation to the remaining histograms) is visible in graphs for dX and dY in Figure 3. For dH in Figure 3 and the remaining differences in coordinates (dX, dY, dH) in Figures 4 and 5, measured frequency in the adopted ranges is stepwise incremental. For deviations dX, dY and dH presented in Figure 3, the highest likelihood of the occurrence of differences in coordinates between the RTX-RTX methods is ±0.005 m. For deviations dX, dY and dH showed in Figures 4 and 5 the highest likelihood of the occurrence of differences in coordinates between the RTK-3rd class CAT. methods and RTX-3rd class CAT. methods is higher or equal to the boundary value of the range ±0.040 m.

3. Conclusion

Although currently developed only to a limited extent, results of the research experiment allow drawing first conclusions on the employment of the Trimble RTX with xFill function technology in low order control network building. Should the GPS rover lose connection with RTK or VRS correction source, the measurement can be continued but with utmost care. Permanent supervision of measurement results, that is monitoring the values of vertical and horizontal errors on the controller screen, as well as time passed since the rover was disconnected from the reference station, allow determination and recording of proper and safe point coordinates of the network in real time using the RTX technology. It follows from the research, that the working time in RTX mode, given by the manufacturer, is longer than the actual time in which RTX technology measurements can be made with the required accuracy. In reality, the time oscillates between 2 and 3.5 minutes. Vertical error of the measured point increases rapidly – two times faster than horizontal errors. Perhaps, if the RTX technology with xFill function were used only for determining X and Y coordinates of the geodetic control network, working time in this mode would equal to 5 minutes or might be even exceeded with the preservation of the required accuracy specified in the regulation (MIA, 2011).

Summing up, the insights drawn from the results of research on the use of the Trimble RTX with xFill function technology in establishing low order geodetic control show, that one might be optimistic about its possible employment in surveying. The technology gives more opportunities, when only horizontal positions of the control points are determined, while determination of spatial coordinates is limited to a shorter time. Conducting further research in the field is well-grounded, as it will allow verification of the real possibilities of employing the technology to establishing local surveying control.

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Weryfikacja przydatności technologii satelitarnej Trimble RTX z funkcją xFill do zakładania osnów pomiarowych

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Streszczenie

W pracy przedstawiono wyniki pomiarów w czasie rzeczywistym punktów osnowy testowej z wykorzystaniem technologii RTK GPS oraz RTX Extended. W technologii Trimble RTX wykorzystano funkcję xFill, która daje możliwości realnego wykonywania pomiaru bez konieczności stałej łączności z siecią stacji referencyjnych systemu ASG EUPOS. Wykonano analizy porównawcze wyników pomiaru między metodami oraz odniesiono je do danych osnowy testowej, przyjętych za bezbłędne. Choć technologia Trimble RTX jest innowacyjną metodą pomiaru i jeszcze rzadko stosowaną, to możliwości jakie daje w realizacjach prac geodezyjnych, w tym zakładaniu osnów pomiarowych, są bardzo zadawalające i z pewnością przyczyni się do jeszcze lepszej i bardziej ekonomicznej organizacji prac geodezyjnych.