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NRTK MEASUREMENTS WITH FKP CORRECTION METHOD IN THE SUBSERVICE NAWGEO OF ASG-EUPOS

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Summary

The paper presents the analysis of the accuracy and repeatability of determining the position of the point by the Network Real Time Kinematic (NRTK) technique using the *Flächenkorrekturparameter* (FKP) concept. The measurement was based on the Active Geodetic Network – European Position Determination System (ASG-EUPOS). The FKP together with Virtual Reference Station (VRS) and Master-Auxiliary Concept (MAC) is the currently available method of generating corrections in NRTK technique in NAWGEO sub-service of ASG-EUPOS. NRTK positioning using FKP was analysed based on Global Positioning System (GPS) and Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS) signals, because the combination of these satellite systems is currently a common standard. The subject of the study was a 24-hour coordinate time series with a sampling interval of 30 seconds. The collected data was compared with the precise coordinates of the measuring point by calculating the linear deviations and the mean values of X, Y and Z coordinates' errors and mean position errors for one-hour periods. Selected measures of positioning accuracy were determined, both for three-dimensional and horizontal coordinates. An analysis of selected dilution of precision (DOP) factors was also carried out. The analyses were also carried out for coordinates expressed in the horizontal coordinate system and normal heights in force in Poland due to the assessment of the suitability of FKP for geodetic measurements. The experiment showed the expediency of NRTK measurements using FKP corrections generated based on observations from the ASG-EUPOS network for determining real-time position within the territory of Poland.

Keywords

NRTK • FKP • ASG-EUPOS • active geodetic network • NAWGEO

1. Introduction

Currently popular measurement techniques used in geodesy are kinematic techniques enabling real-time position determination based on Global Navigation Satellite Systems (GNSS) and reference station networks. These techniques include Real Time Kinematic (RTK) and Network Real Time Kinematic (NRTK), which allow for positioning accuracy down to centimetres. In the RTK technique, the position of a rover (mobile receiver) is determined based on corrections from a single physical reference station. Instead, in the NRTK technique, the position of a rover is determined on the basis of corrections generated with the use of a network of reference stations composed of at least three physical reference stations with an appropriate spatial configuration with respect to the measurement site. Since the late 1990s, many concepts of NRTK measurement methods have been developed, differing in the way they generate and transmit corrections to the rover. The existing concepts of NRTK measurement methods include: Virtual Reference Station (VRS) also known as Pseudo-Reference Station (PRS), Master-Auxiliary Concept (MAC), Individualized Master-Auxiliary Corrections (i-MAX), and German Flächenkorrekturparameter (FKP). Among the most popular and widely used is the VRS method.

One of the earliest NRTK measurement concepts is The Area-Parameter Corrections (FKP – German Flächenkorrekturparameter) method. The FKP method requires the rover to transmit its approximate position to the computing centre of a given network of reference stations. In response to the rover, from the closest reference station – referred to as the master station – the corrected data is transmitted along with network area corrections (FKP) parameters. FKPs are generated for each satellite that is tracked by a rover, and they determine the slope of the correction surface in the N-S and E-W directions, separately for dispersive errors and ephemeris as well as non-dispersive errors. Accordingly, four area correction parameters are determined for each satellite signal received. Thanks to the FKP parameters defining the correction area between the main station and other nearby network stations, it is possible to determine the error values of the coordinate differences between the position of the rover and the position of the main station. Thereby, a vector is determined between the rover and the master station, and the phase uncertainty is resolved, and thus it is possible to determine a correction of the rover position. FKP measurements of NRTK require the use of dual-frequency antennas and receivers. The FKP model taking into account the approximate coordinates of the rover can be described as [Cina et al. 2015]:

$$\text{Non-dispersive term: } \delta_{r0} = 6.37(N_0(\varphi - \varphi_R) + E_0(\lambda - \lambda_R)\cos\varphi_R) \tag{1}$$

$$\text{Dispersive term: } \delta_{rI} = 6.37H(N_I(\varphi - \varphi_R) + E_I(\lambda - \lambda_R)\cos\varphi_R) \tag{2}$$

$$H = 1 + 16(0.53 - E/\pi)^3 \tag{3}$$

where:

φ, λ – rover approximate coordinates,
N_0 – FKP parameter N-S direction, ionospheric delay [ppm],
E_0 – FKP parameter E-W direction, ionospheric delay [ppm],
N_I – FKP parameter N-S direction, tropospheric delay,
E_I – FKP parameter E-W direction, tropospheric delay,
E – satellite elevation [°].

The FKP concept is also used as a supplement to the Differential GPS (DGPS) measurements performed with cheap single-frequency receivers based on the L1 frequency

(1575.42 MHz), due to its simplicity and the lack of need for detailed data on the reference station network. Additionally, the use of the FKP concept modification in DGPS measurements makes it possible to reduce positioning errors caused by spatial decorrelation, and it improves positioning accuracy by up to 40% [Kim et al. 2017].

The accuracy and correctness of the results obtained with the RTK and NRTK methods are influenced by, among other things: clock errors, satellite orbit errors, accuracy of ionospheric and tropospheric delay determination, and local effects. Accuracy, repeatability, and reliability of NRTK measurements under various observational conditions have been the subject of many studies. Attention is paid not only to the choice of the NRTK measurement method itself, but also to the influence of ionospheric activity [e.g. Bae and Kim 2018], the number of satellites observed [e.g. Pehlivan et al. 2019], and the geometry of the base station network [e.g. Grejner-Brzezinska et al. 2005, Cina et al. 2015]. The NRTK technique contributed to the improvement in the reliability of real-time measurements and the elimination of the limitation in the previously performed RTK measurements, which was the decrease in the accuracy of RTK measurements along with the increase in the distance between the network rover (mobile receiver) and the physical reference station (base station). As reported by Baybura et al. [2019] with the current technological development, including the improvement in the transmission of corrections, the RTK and NRTK techniques make it possible to achieve equally accurate measurement results up to a distance of approximately 40 km from the base station, while above this distance, the NRTK allows for better measurement accuracy than RTK. At the same time, as noted by Próchniewicz et al. [2016], there are many indices describing the reliability of NRTK positioning in terms of modelling ionospheric and geometric errors of the network (including tropospheric refraction and orbit errors) for the entire area of the network of reference stations, called solution quality indicators. However, these indicators are not related to the basic parameters describing the quality of positioning, i.e. the correctness of the rover's initialisation, and the accuracy of the position of the rover in relation to the real position [Próchniewicz et al. 2016]. Studies comparing FKP and VRS methods with MAC have shown that the MAC method is characterized by high reliability in determining the uncertainty and accuracy, and offers the highest efficiency in terms of uncertainty determination time [Brown et al. 2005]. In the situation of limited sky visibility (the cut-off angle of the horizon at 30° and 40°), the FKP method is characterized by lower precision and repeatability of the horizontal position determination than the VRS method [e.g. Pehlivan et al. 2019]. The FKP method using only the GPS system is characterized by a greater sensitivity to ionospheric disturbances than the VRS method, therefore it is recommended to also use the GLONASS system signals [e.g. Bae and Kim 2018]. However, if the uncertainty of the statistics is resolved correctly, the levels of position accuracy determined using FKP and VRS methods are similar.

Due to the fact that the accuracy of the NRTK measurements should be considered as a function of the geometry of the reference stations network, the distance between the stations, and the choice of the data processing strategy [e.g. Grejner-Brzezinska et al. 2005], it is recommended that the distances between the reference stations in the

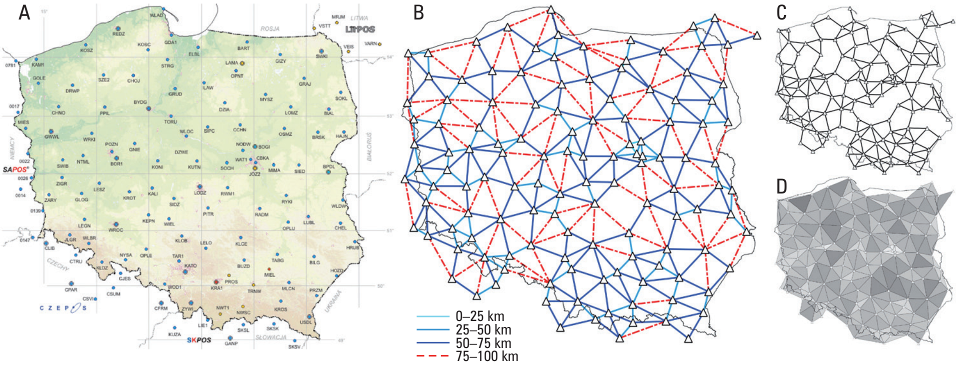
NRTK network be between 50 and 70 km [e.g. El-Mowafy 2012, Koivula et al. 2018]. As a result, most countries developed their own national reference station networks to enable NRTK measurements. In the case of Central and Eastern European countries, national networks of reference stations were created in accordance with the European Position Determination System (EUPOS) standards, which assume that the average distance between stations is less than 75 km. National systems based on the EUPOS standard obligatorily provide the possibility of using NRTK measurements with the application of the non-physical reference station concept (i.e. PRS, VRS, etc.) as well as MAC [Technical Standard EUPOS 2013]. An example of such a system is the Active Geodetic Network – European Position Determination System (ASG-EUPOS), which is the Polish national network of reference stations consisting of 127 stations evenly distributed throughout the territory of Poland and in the trans-border areas of neighbouring countries. The ASG-EUPOS network is used to implement the three-dimensional PL-ETRF2000 system for the epoch 2011.0 in Poland, which is an implementation of the European Terrestrial Reference System (ETRS89) applicable in Europe and implemented through the EUREF Permanent GNSS Network (EPN) station. The ASG EUPOS system enables RTK and NRTK measurements using the VRS, FKP and MAC methods. Networks compliant with the EUPOS standard also often enable NRTK measurements using the FKP method (e.g. the German SAPOS).

NRTK methods are used in geodetic surveying, in precision agriculture, in monitoring the position of objects, and in many other aspects when there is a need for accurate positioning. NRTK measurements and data from terrestrial laser scanning can also be used to update the base map [Klapa and Mitka 2017] and enable comprehensive control of the geometry of buildings at each stage of their construction [Klapa et al. 2018]. As noted by Bae and Kim [2018], the NRTK methods are also used in the positioning of unmanned aerial vehicles (UAVs), with the need for object positioning accuracy in motion below 1 m.

Accordingly, there is a need to assess the accuracy, precision, and reliability of NRTK methods in order to provide reference network users with comprehensive information on real-time correction streams. The accuracy of the NRTK methods should be understood as the compliance of the measurement results with the actual values. On the other hand, the precision of the NRTK methods should be considered as the consistency of the results obtained from multiple measurements of the same points, i.e. the degree of dispersion (spread) of the measurement results. The precision of the NRTK methods in the case of the participation of the same observer and the measuring apparatus can be defined as the repeatability of the NRTK methods. The aim of the research undertaken and reported in this article was to analyse the accuracy and repeatability of determining the three-dimensional position using the NRTK technique, applying the FKP method based on the ASG-EUPOS reference station network. The test measurement was carried out for one measuring point on which positions were recorded over 24 hours, with a 30-second recording interval. The measurement was performed with the use of GPS and GLONASS satellite signals due to the fact that the combination of these two satellite systems should be considered as a standard of the current positioning applying the NRTK technique. At the same time, it should be noted that currently, in most areas of the ASG-EUPOS network, corrections generated on the basis of signals from more systems (GPS + GLONASS + BDS + GALILEO) are already available.

2. Material and methods

The measurement experiment was carried out using the FKP method and the ASG-EUPOS network. In order to approximate the geometry of the ASG-EUPOS network (Fig. 1A), its spatial analysis was performed using Delone triangulation (Figures 1B, C, D).



Source: www.asgeupos.pl (A), Authors' own elaboration (B, C, D)

Fig. 1. ASG-EUPOS network: location of reference networks (A), classification of distances between the stations (B), distances not exceeding 75 km (C), area of triangles with apexes in the points of the network (D)

The generated triangles can be equated with the minimum cells of the reference network based on which the NRTK corrections are generated. The sides of the triangles larger than 100 km were removed from the analysis due to the fact that, according to the EUPOS standard, the distance between the two closest stations cannot exceed 100 km [Technical Standard EUPOS 2013], as were the triangles that do not coincide with the territory of Poland. The distances between the stations not exceeding 100 km are shown in Figure 1B, while distances not exceeding 75 km are shown in Figure 1C. In 75% of the cases shown in Figure 1B, the distances are up to 75 km, whereas about 48% are distances between 50 and 75 km. The average value of the presented distances is approximately 62 km. The average area of the triangles is 1477 km2, and about 59% are triangles with an area of 1000 to 2000 km2 (Fig. 1D).

The 24-hour measurement with a sampling interval of 30 seconds was carried out on days 142 and 143 of 2017 (142-143 DOY 2017) using a receiver integrated with the Trimble R8 Model 3 GNSS/SPS88x Internal antenna, and Trimble General Survey 2.50

measurement software. The recording of three-dimensional positions (*X*, *Y*, *Z*) in the PL-ETRF2000 coordinate system was started at 9:39 on 142 DOY 2017 at a specially prepared measuring point with forced centring in the Wieliczka district (*poviat*). The precise coordinates of the measurement point (X_R, Y_R, Z_R) were obtained as a result of aligning the static satellite observations from two 12-hour measurement sessions in relation to the nearby ASG-EUPOS network stations. The FKP patch in RTMC 3.1 format was used, available on the NAVGEO_FKP_3_1 stream (IP 91.198.76.2:2101) made available under the NAVGEO subservice of the ASG-EUPOS system. The correction was generated based on GPS+GLONASS signals. The value of the elevation mask was 5°, and the acceptable PDOP value was 6. Before commencing the measurement, the correctness of the receiver initialization was verified relative to two nearby points of the national network with known coordinates (Nos. 712312.1.11090 and 712312.1.11100). The location of the measurement site in relation to six nearby ASG-EUPOS network reference stations is shown in Figure 2. The closest reference station was the KRA1 station located in Kraków (No. 173.112-1810). The length of the 3D vector to the KRA1 station was 15,611 m.

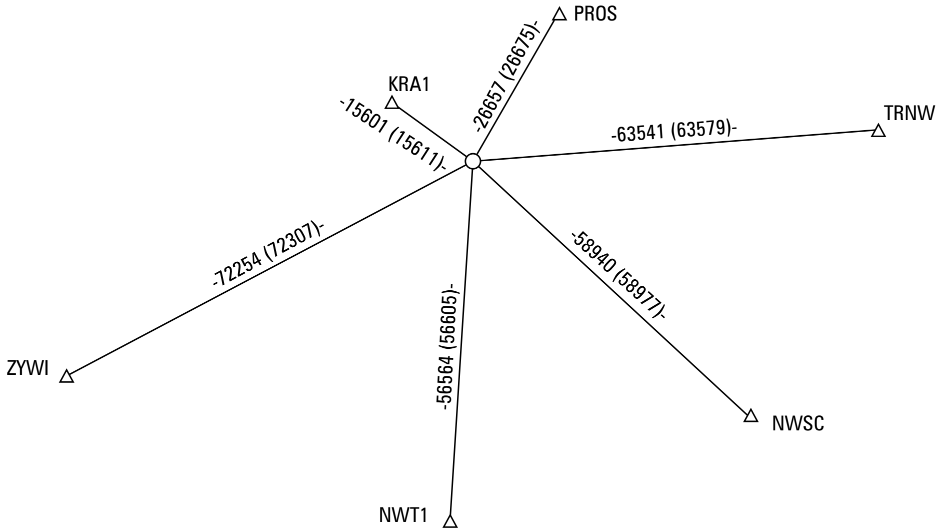


Fig. 2. The position of the measuring point against the background of the ASG-EUPOS's stations (the length of the 3D vectors in brackets)

During the measurement, the registration also included the values of the dilution of precision (DOP) coefficients: position (3D) dilution of precision (PDOP), vertical dilution of precision (VDOP), and horizontal dilution of precision (HDOP), in order to characterize the observation conditions at the measuring point. The DOP coefficients take into account the configuration of the positions of the satellites in relation to each other, and their geometrical relationship with the antenna of the satellite receiver. A lower DOP value indicates a higher probability of high positioning accuracy. The most commonly used DOP is PDOP, which is a dimensionless value expressing the quality of the relationship between the error in determining the position of the measurement antenna, and the error in determining the position of the satellites involved in the positioning. The values of Root Mean Square (RMS), which is one of the Quality Check (QC) parameters, i.e. the parameters of accuracy and reliability of position determination, were also registered. The RMS value depends on the observation time of the baseline and its length. High RMS values may indicate that disturbances have occurred, including the multipath phenomenon, among others.

The data constituting the series of three-dimensional coordinates X_i, Y_i, Z_i was then transformed into a series of linear deviations (ΔX_i, ΔY_i, ΔZ_i), which were obtained as differences between the recorded and reference coordinates. Based on the linear deviations, the mean error of a single observation for each coordinate (m_X, m_Y, m_Z) was determined, as well as the error of the point position (m_p), and the length of the vectors between the recorded positions and the reference position. The set of positions was assessed in terms of the distance from the reference point in intervals of 0.01 m. In this way, a one-dimensional analysis of the set of positions in the defined distance space from the reference point was performed. Standard deviations of the recorded coordinates in relation to the reference coordinates were used to calculate the measurement accuracy of the FKP NRTK method in the ASG-EUPOS system, i.e. spherical error probable (SEP), mean radial spherical error (MRSE), 90% spherical accuracy standard (SAS90), and 99% spherical accuracy standard (SAS99). These measures determine the 3D accuracy of a position with a probability of 50%, 61%, 90%, and 99% relative to the reference position, respectively. The value of the applied accuracy measures represents the radius of the sphere with the geometric centre in the reference position, in which the positions obtained during the experiment occur with the assumed probability. The value of the MRSE, SEP, SAS90, and SAS99 measures was determined according to the following formulas [e.g. Leick et al. 2015]:

$$SEP = 0.5127(\sigma_X + \sigma_Y + \sigma_Z) \tag{4}$$

$$MRSE = \sqrt{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2} \tag{5}$$

$$SAS90 = 0.833(\sigma_X + \sigma_Y + \sigma_Z) \tag{6}$$

$$SAS99 = 1.122(\sigma_X + \sigma_Y + \sigma_Z) \tag{7}$$

The X, Y, Z three-dimensional coordinates were also converted to the horizontal coordinate system of PL-2000 zone 7 (EPSG 2178), and the PL KRON86-NH normal height system, which are applicable in Poland. In order to determine normal heights, the model of the PL-geoid-2011 quasi-geoid applicable in Poland was used, which is the result of the calibration of the global EGM2008 model based on the altitude network points located in Poland and points determined by satellite techniques (as result of a calibration of global EGM2008 model on satellite and levelling networks) [Kadaj and

Świętoń 2016]. For the horizontal coordinates (x, y), the value of distance root mean square (DRMS) was specified, which is a measure of the accuracy of a 2D position with a probability of 63.2% [e.g. Leick et al. 2015]:

$$DRMS = \sqrt{\sigma_x^2 + \sigma_y^2} \tag{8}$$

Statistical analyses were performed in the *R* programming environment [*R* Core Team 2018] and with the use of the plot3D library [Soetaert 2014] for data visualization. The analyses used coordinates with a recording accuracy of 0.001 m.

3. Results

The analysis of satellite observation conditions with the use of the DOP coefficients (Fig. 3) showed that the PDOP value varied in the range from 1.09 to 1.88, the HDOP coefficient value varied in the range from 0.60 to 1.02, and the VDOP coefficient value ranged from 0.84 to 1.69. The mean values of the coefficients for the analysed period were 1.33, 0.72, 1.11 for PDOP, HDOP and VDOP, respectively. Due to the fact that the values reached by the coefficients were low, it can be concluded that during the recording of the measurement point position favourable observation conditions prevailed regarding the configuration of the tracked satellites in relation to the antenna of the satellite signal receiver. Despite the low values of the analysed DOP coefficients, during the experiment, it is possible to indicate moments when they increased, which took place around 12-13 DOY 142 and 6-7 DOY 143.

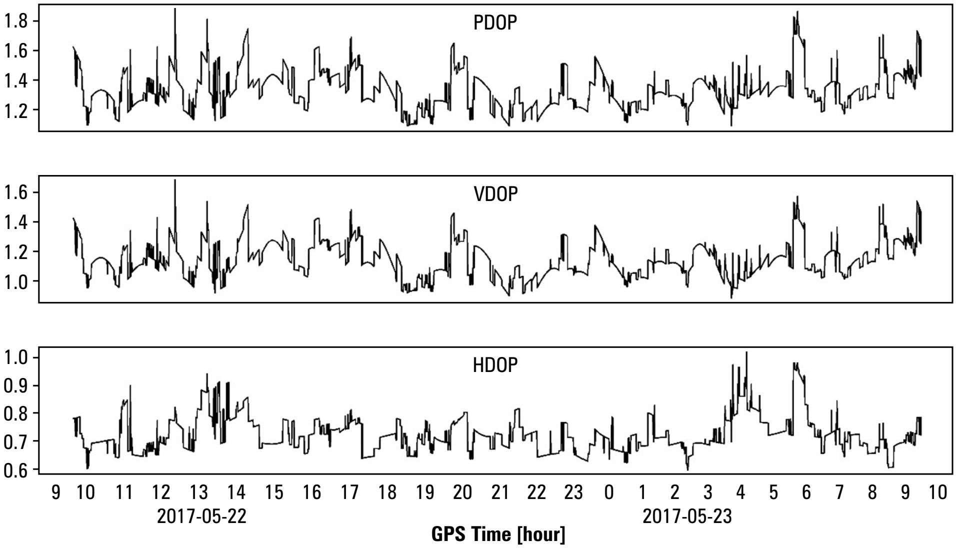


Fig. 3. Values of PDOP, VDOP, and HDOP at the point of measurement during the measurement period

In the case of the RMS coefficient, its mean value was about 40 millicycles (Fig. 4). During the measurement period, increased RMS values (larger than 70 millicycles) were recorded for approximately 2% of the observations. This is important as RTK measurements using only GPS signals are not recommended for RMS values greater than 70 millicycles [Guyer 2015]. Such values were recorded for the following time periods on 142 DOY 2017: 19:13–19:16, 19:41–19:51, and on 143 DOY 2017: 4:11–4:12, 4:28–4:41, 9:28–9:31.

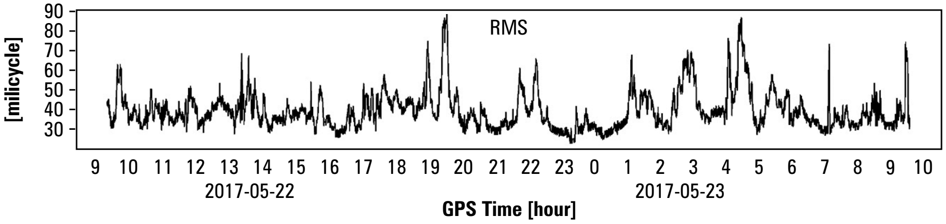


Fig. 4. RMS change at the point of measurement during the measurement period

During the measurement, 2880 positions of the measurement point were recorded, from which the coordinates of the reference position were subtracted. In this way, a series of linear deviations was obtained, being the resultant of the accuracy of the FKP NRTK measurements stemming from the measurement conditions during the experiment. The linear deviations of the recorded coordinates are shown in Figure 5. In the case of the *X* coordinate, the linear deviations ranged from −0.067 to 0.023 m, while the standard deviation reached the value of 0.008 m. The mean value of the linear deviation of the *X* coordinate was −0.003 m. In the case of the *Y* coordinate, the linear deviations ranged from −0.044 to 0.013 m, and their mean value was −0.004 m, while the standard deviation was 0.005 m. In turn, in the case of the *Z* coordinate, the linear deviations ranged from −0.049 to 0.018 m, the mean value of the linear deviation was −0.014 m, and the standard deviation was 0.010 m. Thus, it should be stated that the highest precision is attributable to the measurement of the *Y* coordinate. The most diverse are the linear deviations of the *X* coordinate, which are characterized by a range of 0.09 m.

In the case of the evaluation of mean errors performed for one-hour periods, it should be stated that the mean error of a single observation of the *X* coordinate was in the range from 0.004 to 0.018 m, for the *Y* coordinate from 0.03 to 0.012 m, and for the *Z* coordinate from 0.009 to 0.029 m. Therefore, the error in the position of the point in the three-dimensional space ranged from 0.013 to 0.031 m. The averaged values of the one-hour mean errors of a single observation for the 24 hours of the experiment were: 0.008 m for the *X* coordinate, 0.006 for the *Y* coordinate, and 0.016 m for the *Z* coordinate. In turn, the mean error of point position over the 24 hours of the experiment was 0.019 m.

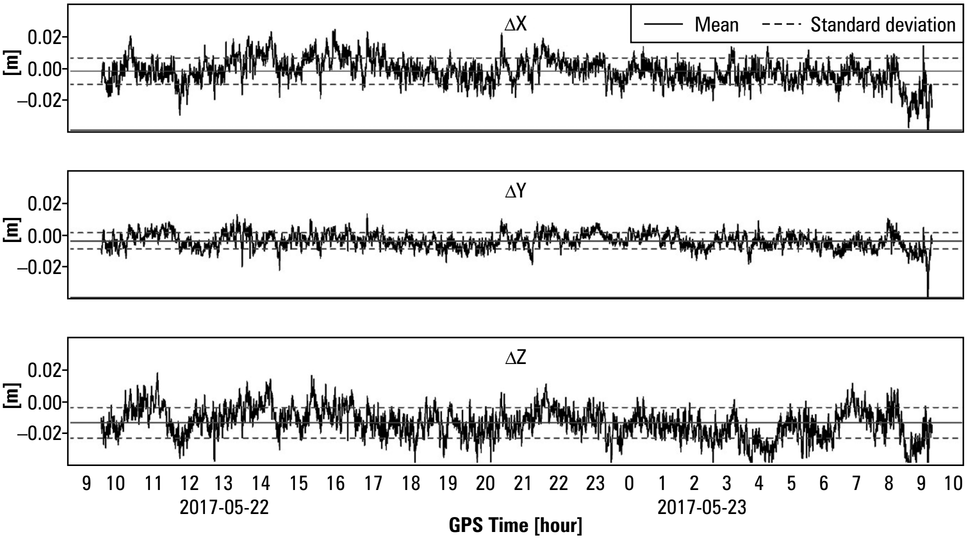


Fig. 5. The time series of residuals ΔX, ΔY and ΔZ during 24 h

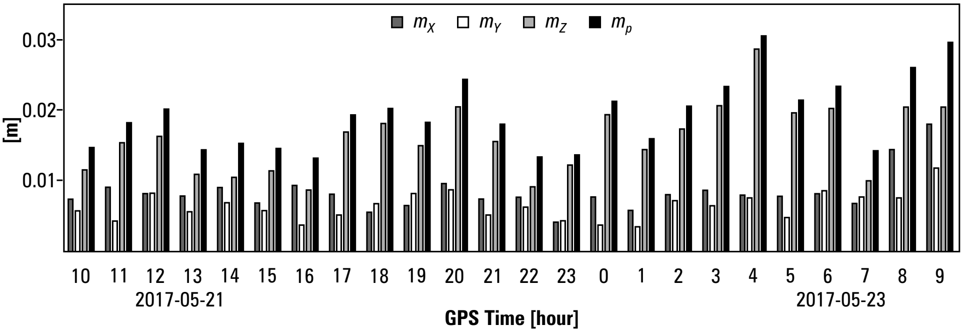


Fig. 6. Mean errors of single measurements of FKP NRTK in the ASG-EUPOS system, for hourly periods

In order to determine the spatial distribution of the recorded positions, graphs were drawn showing their location around the reference position in the planes of the PL ETRF2000 system (Fig. 7). The plots show that the spatial distribution of points in individual planes takes a shape similar to an ellipse. At the same time, the analysed items were classified depending on the distance from the reference position. The distance between the recorded positions and the reference position ranges from 0.001 m to 0.091 m and reaches an average value of 0.018 m. For 25% of the positions, the distance between the recorded positions and the reference position ranged between of 0.00–0.01 m; for 46.2% of the positions, between 0.01–0.02 m; for 21% of the positions, between 0.02–0.03; for 6.2% of the positions, between 0.03–0.04; for 1.2% of the positions, between 0.04–0.05 m; and for 0.4% of the positions, distance between the recorded positions and the reference position was larger than 0.05 m. Having analysed the percentage share of positions in individual distance ranges from the reference position, we can conclude that the measurement turned out to be accurate, because 92.2% of the positions were located at a distance of ≤0.03 m.

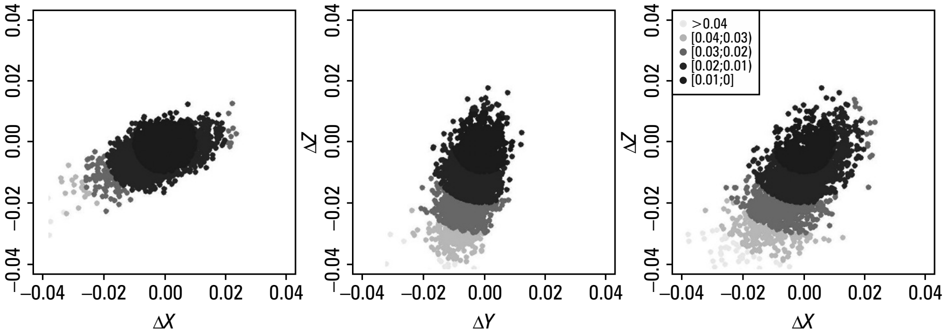


Fig. 7. Location of the recorded positions in the *XY*, *YZ*, and *XZ* planes

SEP values calculated on the basis of positions recorded during one-hour periods ranged from 0.007 to 0.015 m; the MRSE values ranged from 0.008 to 0.018 m; the SAS90 values ranged from 0.012 to 0.024 m; whereas the SAS99 values ranged from 0.016 to 0.033 m. Upon analysing Figure 8, it can be concluded that the accuracy measures present the highest values for the 8th and 9th hours of measurement on 143 DOY 2017. By averaging the values of one-hour accuracy measures for the 24 hours of the experiment, the obtained SEP was 0.010 m, MRSE was 0.011 m, SAS90 was 0.015 m, and SAS99 was equal to 0.021 m.

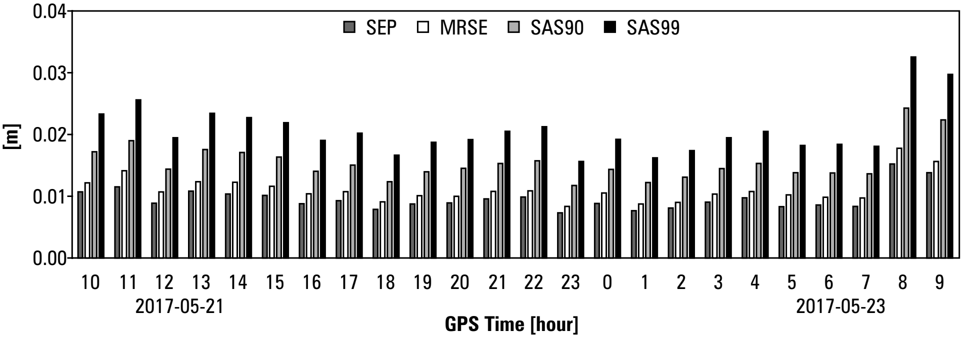
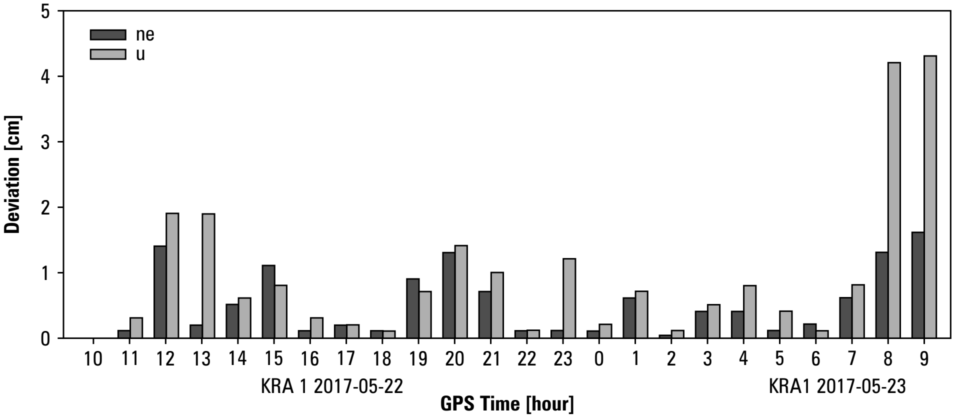


Fig. 8. Accuracy measures for FKP NRTK measurements in the ASG-EUPOS system for hourly periods

In addition, the operational performance of the FKP NRTK method was compared with the data on the accuracy of real-time streams specified under EUPOS Service

Quality Monitoring (http://monitoringeupos.gku.sk/) based on software developed by the Geodetic and Cartographic Institute from Bratislava. Data informing about the deviation of the coordinate values obtained from the RTK measurement from the known coordinates of the KRA1 reference station of the ASG EUPOS system located closest to the measurement point was used (Fig. 9). These data show a decrease in the accuracy of the altitude component measurement on 142 DOY 2017 for 12th and 13th hours, and on 143 DOY 2017 for 8th and 9th hours. Decreased accuracy in the analysed period is also observed on 143 DOY 2017 for 08:00 and 09:00 o'clock (Fig. 9). The indicated periods of decreased accuracy coincide in most cases with periods in which increased values of DOP coefficients were recorded, as well as higher values of SEP, MRSE, SAS90, and SAS99 and position error (mp). This is especially true for the 8th and 9th hours on 143 DOY 2017.



Source: http://monitoringeupos.gku.sk/

Fig. 9. RTK measurement accuracy in the area of the KRA1 station, according to the Service Quality Monitoring project

In order to assess the usefulness of NRTK measurements with the use of the FKP correction for the needs of geodetic measurements, the accuracy and dispersion of the recorded positions in the PL 2000 plane coordinate system and the PL KRON86-NH altitude coordinate system, which are currently used for the purposes of geodetic work (Fig. 10), were assessed. The analysis of plane coordinates showed that the recorded positions turned out to be shifted relative to the reference position in the south-westerly direction. Their average distance from the reference point was 0.008 m. In the case of the normal height values (H) of the recorded positions, we concluded that the measured positions are characterized by altitudes lower on average by 0.013 m than the reference point, whereas 93% of the recorded positions were within the distance of ≤0.03 m in relation to the reference position, including 73% of the recorded positions within the distance of ≤0.02 m. The mean error of a single observation for the H coordinate was 0.018 m, while the error of the point position in the plane coordinate system PL-2000 was 0.011 m. The DRMS values calculated for one-hour periods took values from 0.005 to 0.008 m, and for the entire 24-hour measurement, amounted to 0.007 m. According to the EUPOS Technical Standards [2013], the NRTK subservices should provide an error in determining the horizontal position of ≤0.02 m. In the case of errors in the recorded positions indicated by the receiver software, the position error in the PL-2000 horizontal coordinate system took values from 0.010 to 0.042 m, with an average value of 0.016 m. For about 85% of the positions, this error did not exceed 0.02 m, whereas the error of height ranged from 0.016 to 0.062 m, and its average value was 0.025 m. For about 87% of the positions, the error remained below 0.03 m; and for 99%, it was below 0.05 m.

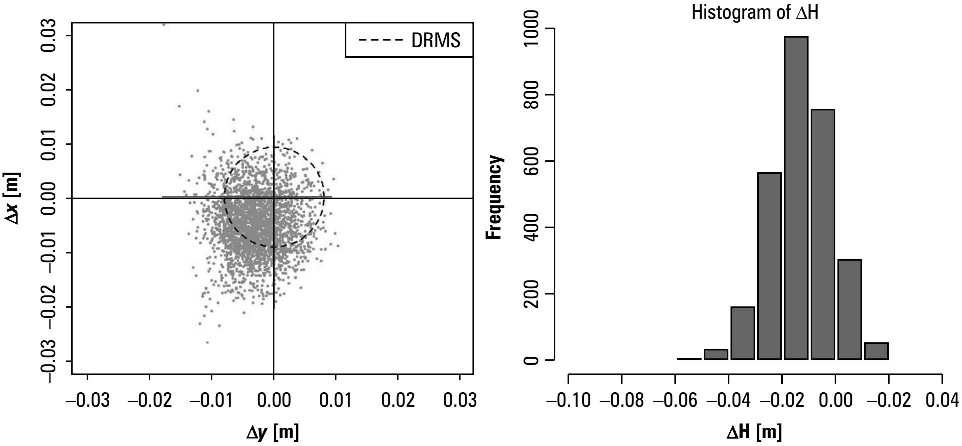


Fig. 10. Scatterplot of the recorded positions in the horizontal coordinate system PL-2000 zone 7 and in the altitude layout PL-KRON86-NH versus reference coordinates

4. Conclusions

The research material collected in the course of the measurement experiment using the FKP NRTK method make it possible to conclude that for 99% of the cases, a three-dimensional position was achieved with an error of ≤0.021 m, which is confirmed by the SAS99 measures and the m_p position error calculated on the basis of mean errors of a single observation of coordinates, amounting to ±0.02 m. Moreover, the ASG EUPOS network infrastructure was characterized by stable operation, which translated into uninterrupted and stable determination of the measurement point position during the 24-hour measurement experiment using FKP corrections and NAWGEO subservice. The analysis of plane coordinates in the Polish horizontal coordinate system (PL-2000) warrants the conclusion that the measurements of NRTK with the use of FKP corrections are characterized by accuracy consistent with the assurances of the ASG EUPOS network manager, declaring the accuracy of horizontal positions at ±0.03 m, because the point position error and the DRMS measure amounted to about 0.01 m. In the case of the altitude layout coordinates, an average error of 0.018 m was obtained, which proves that the results were consistent with the declared accuracy of ±0.05 m. It should be noted, however, that in most cases the obtained values were lower than the actual ones. It should also be taken into account that the accuracy of NRTK measurements with FKP corrections presented in this article may vary under different observational conditions.

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