RESEARCH ARTICLE

Assessment of the Usefulness of Egnos Differential Corrections in Conducting Gps Static Measurements

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ABSTRACT
The article presents the results of research in determining the position of the base station in a static mode using EGNOS differential corrections. The experiment was conducted in the Dęblin airport area. The experiment comprised determining the coordinates of three base stations (REF1, VirA i VirB). The analysis of the results for the tools adopted pointed out to the fact that the accuracy of coordinate determination for each station was in the range of less than 2 meters.
Keywords: GPS, GNSS, EGNOS

I. INTRODUCTION

GNSS satellite technique is a universal positioning method, used in air, marine, and land navigation. At present, the Global Navigation Satellite System (GNSS) comprises four navigation systems, i.e.: GPS, GLONASS, GALILEO, and BEIDOU [8, 9]. Ultimately, for all of the systems mentioned above, the user's position error should not exceed 10 meters with a probability of 95% [10]. Increasing the accuracy of the user's position, in both static and kinematic mode, is possible with the use of the SBAS support systems. Furthermore, the Japanese QZSS-Zenith navigation system may also be included to the SBAS system [7]. SBAS support systems are mainly used to increase the positioning accuracy of the GPS and GLONASS navigation systems. A common characteristic of the SBAS support systems is the transmission of differential corrections aimed at eliminating, or significantly reducing, systematic errors which affect the value of the user's coordinates being determined. Because of the use of SBAS differential correction, it is possible to achieve the accuracy of the user's position in the range of less than 5 meters [7].

The article presents preliminary results of the research in the use of differential corrections received from the EGNOS system in GPS static measurements. The experiment was conducted in the Dęblin airport area. The objective of the experiment was to determine the accuracy of the reference station's coordinates after applying EGNOS corrections, and to compare the measured coordinates with the results in the directory. The experiment was conducted for three reference stations (REF1, VirA oraz VirB).

II. RESEARCH METHODOLOGY

The research methodology was based on the application of the SCP (Single Point Positioning) method to determine the coordinates of reference stations. The basic observational equation for the SPP method was written in the form [6]:

$$C1 = \rho + C \cdot \left(dto - dts \right) + Ion + Trop + Rel + TGD + PRC$$

(1)

where:

$C1$ - L1 C/A code measurement in the GPS system,

ρ - geometric distance between the satellite and the receiver,

$$\rho = \sqrt{\left(x - X_{GPS}\right)^2 + \left(y - Y_{GPS}\right)^2 + \left(z - Z_{GPS}\right)^2}$$

,

(x, y, z) - aircraft position in a geocentric system,

$(X_{GPS}, Y_{GPS}, Z_{GPS})$ - GPS space vehicle (SV) position in the orbit,

C - speed of light,

dto - receiver clock error,

dts - SV clock error,

Ion - ionospheric correction,

$Trop$ - tropospheric correction,

Rel - relativistic correction (mostly orbital eccentricity),

TGD - SV hardware delay for L1 code measurement,

PRC - Differential correction from EGNOS SVs.

In equation (1) the unknown parameters are increments of the approximate coordinates of the aircraft (3 parameters) and the receiver clock error correction (1 parameter). The unknown parameters from equation (1) are determined using the least-squares method (LSM) in a sequential process for all measurement epochs, as shown below [12]:

$$\begin{cases} x = N^{-1} \cdot L \\ v = A \cdot x - l \\ m0 = \sqrt{\dfrac{[Pvv]}{n-k}} \\ m_{XYZ} = m0 \cdot \sqrt{N^{-1}} \end{cases} \quad (2)$$

where:
x- vector of parameters to be estimated,
N- matrix of the standard equation system,
$N = A^T \cdot P \cdot A$,
A - coefficient matrix,
P- matrix of weights,
l- vector of observations,
v- vector of corrections,
L - vector of free terms;
$L = A^T \cdot P \cdot l$,
m0- unit mean error,
n- number of measurements,
k - number of parameters determined,
$k = 4$,
m_{XYZ}- mean errors of the parameters determined in the geocentric system XYZ.

III. COURSE OF THE RESEARCH EXPERIMENT AND ITS RESULTS

The experiment consisted of three research tests performed in order to determine the base station positioning accuracy after the application of EGNOS differential corrections. The coordinates of each base station were then compared with coordinates extracted from the RINEX file header. The research experiment was conducted in the morning in the Dęblin airport area. For the purposes of the experiment, three reference stations (REF1, VirA, and VirB) were deployed to secure air operations and monitor the changes of the aircraft position (flight test involving the Cessna 172).

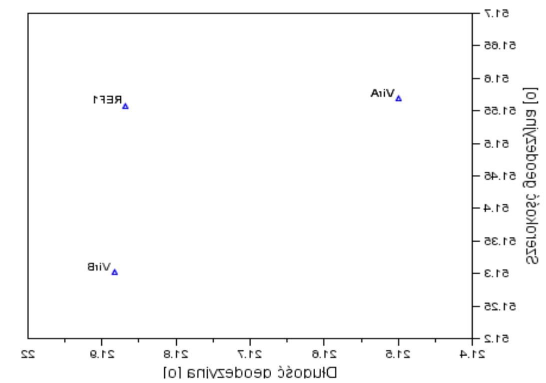

Fig.1 Arrangement of base stations in the experiment.

REF1 reference station was an actual physical reference station (CORS), in which a dual frequency Topcon TPS Hiper receiver was installed that recorded GPS/GLONASS observations with 1 second interval. VirA and VirB base stations were local reference stations, deployed for the purpose of the research experiment. VirA and VirB stations were equipped with TRIMBLE NETRS receivers (with TRM41249.00 TZGD antennas) which recorded only GPS observations with 1 second interval. Location of REF1, VirA, and virB reference stations in geodetic coordinates B and L (geodetic latitude and longitude) is shown in Fig. 1. The coordinates of the REF1, VirA, and VirB base stations were accurately determined in ETRF'89 (European Terrestrial Reference Frame 1989) geocentric system, and they are listed in Table 1

Table 1. Catalog coordinates of REF1, VirA, VirB reference stations in ETRF'89 system.

Reference station	Parameter	Coordinate value [m]
REF1	X coordinate	3687929,1998
	Y coordinate	1480229,4605
	Z coordinate	4972323,7996
VirA	X coordinate	3696489,0264
	Y coordinate	1456085,7505
	Z coordinate	4973095,4807
VirB	X coordinate	3708190,7801
	Y coordinate	1489430.2983
	Z coordinate	4954599.0296

The Topcon TPS Hiper receiver in the REF1 station was collecting satellite observations from 09:40:20 to 10:36:53, and the TRIMBLE NETRS receivers in the VirA and VirB stations from 09:35:00 to 10:44:59 respectively, according to GPS Time. Topcon TPS Hiper recorded code observations (P1, C1, and P2), phase observations (L1 and L2), and Doppler observations (D1 and D2). TRIMBLE NETRS receivers, on the other hand, recorded code observations (C1 and P2), phase observations (L1 and L2), and the signal-to noise ratio SNR (S1 and S2).

During the experiment, coordinates of three reference stations were determined using EGNOS correction. EGNOS differential corrections, in the form of "EMS" text files [5], were downloaded from a Web server, http://www.egnos-pro.esa.int/ems/index.html. The coordinates of individual base stations were determined using differential corrections received from the EGNOS satellites: S120, S124, and S126. The coordinates of the three base stations were computed in the RTKLIB (RTKPOST module) program package [14]. For the purpose of the research tests performed, RTKPOST module was configured for the EGNOS system, as follows [2]:
- positioning type: SPP,

- elevation mask: 10^0,
- ionospheric correction source: SBAS,
- tropospheric correction source: SBAS,
- source of ephemeral data: Broadcast message and SBAS,
- satellite systems used for the computations: GPS i SBAS,
- reference system: geocentric ECEF (XYZ),

The results of the experiments are presented in Tab. 2, 3, and 4. These tables show the mean error values in the determination of the XYZ coordinates for individual reference stations (REF1, VirA, andVirB) after applying EGNOS differential correction.

Table 2. Coordinate calculation accuracy for the REF1 base station.

Parameter	**Differential correction source EGNOS S120**	**Differential correction source EGNOS S124**	**Differential correction source EGNOS S126**
X coordinate mean error (Mx)	1.695 m (dispersion of results from 1.031 m to 3.019 m)	1.685 m (dispersion of results from 1.093 m to 3.019 m)	1.297 m (dispersion of results from 0.792 m to 2.199 m)
Y coordinate mean error (My)	0.939 m (dispersion of results from 0.757 m to 1.201 m)	0.940 m (dispersion of results from 0.757 m to 1.201 m)	0.733 m (dispersion of results from 0.499 m to 1.104 m)
Z coordinate mean error (Mz)	1.826 m (dispersion of results from 1.334 m to 2.681 m)	1.830 m (dispersion of results from 1.332 m to 2.681 m)	1.406 m (dispersion of results from 0.949 m to 2.337 m)
Point positioning error in 3D space (Mp)	2.689 m (dispersion of results from 1.894 m to 3.577 m)	2.684 m (dispersion of results from 2.006 m to 3.577 m)	2.059 m (dispersion of results from 1.343 m to 3.199 m)

Table 3. Coordinate calculation accuracy for the VirA base station.

Parameter	**Differential correction source EGNOS S120**	**Differential correction source EGNOS S124**	**Differential correction source EGNOS S126**
X coordinate mean error (Mx)	1.766 m (dispersion of results from 1.032 m to 3.134 m)	1.767 m (dispersion of results from 1.094 m to 3.134 m)	1.331 m (dispersion of results from 0.793 m to 2.198 m)
Y coordinate mean error (My)	0.955 m (dispersion of results from 0.748 m to 1.229 m)	0.957 m (dispersion of results from 0.748 m to 1.238 m)	0.749 m (dispersion of results from 0.497 m to 1.166 m)
Z coordinate mean error (Mz)	1.799 m (dispersion of results from 1.320 m to 2.676 m)	1.805 m (dispersion of results from 1.331 m to 2.677 m)	1.398 m (dispersion of results from 0.948 m to 2.335 m)
Mean Radial Spherical Error (Mp)	2.733 m (dispersion of results from 1.894 m to 3.688 m)	2.738 m (dispersion of results from 2.005 m to 3.689 m)	2.087 m (dispersion of results from 1.342 m to 3.235 m)

Table 4. Coordinate calculation accuracy for the VirB base station.

Parameter	**Differential correction source EGNOS S120**	**Differential correction source EGNOS S124**	**Differential correction source EGNOS S126**
X coordinate mean error (Mx)	1.771 m (dispersion of results from 1.034 m to 3.133 m)	1.772 m (dispersion of results from 1.096 m to 3.133 m)	1.333 m (dispersion of results from 0.794 m to 2.198 m)
Y coordinate mean error (My)	0.955 m (dispersion of results from 0.749 m to 1.229 m)	0.958 m (dispersion of results from 0.749 m to 1.238 m)	0.750 m (dispersion of results from 0.499 m to 1.165 m)
Z coordinate mean error (Mz)	1.804 m (dispersion of results from 1.320 m to 2.670 m)	1.809 m (dispersion of results from 1.330 m to 2.670 m)	1.402 m (dispersion of results from 0.947 m to 2.338 m)
Mean Radial Spherical Error (Mp)	2.738 m (dispersion of results from 1.894 m to 3.687 m)	2.734 m (dispersion of results from 2.005 m to 3.687 m)	2.090 m (dispersion of results from 1.342 m to 3.268 m)

It was determined in the research experiment that the average mean error of the X coordinate for each reference station amounted to less than 2 m (based on the differential corrections received from S120, S124, and S126 satellites). When differential corrections from the S126 satellite were used, the mean error of the X coordinate was approximately 1.3m for each reference station. The use of differential correction received from the S120 and S124 satellites resulted in the mean error of the X coordinate being approximately 1.7 m for each of the three base stations.

The mean error of the Y coordinate is less than 1 m for the REF1, VirA, and VirB stations (after the application of the EGNOS differential correction). *It should be stressed that the use of corrections received from the S126 satellite reduces the accuracy of the Y coordinate to approximately 0.75m.* Differential correction from the S120 and S124 satellites allows the achievement of the Y coordinate accuracy of about 1 m for each reference station. The accuracy of calculating the Z coordinate was in the experiment under consideration less than 2 m for all three base stations. It is worth noting that the differential corrections received from the S126 a satellite allow the achievement of an average accuracy of the Z coordinate at approximately 1.4m. On the other hand, differential corrections from the S120 and S124 satellites allow the achievement of an average accuracy of the Z coordinate at approximately 1.8 m. Tables 2, 3, and 4 also show the Mean Radial Spherical Error [13] (Mp) for all reference stations. The value of the parameter Mp for each reference station is approximately 2 meters after the application of the differential correction received from the S126 satellite, and approximately 2.7 m when the differential correction was received from S120 and S124. It should be noted that the difference of the parameter Mp after applying the EGNOS correction received from satellite S126 and satellites S120 and S124 is fairly significant, being approximately 0.7 m.

In the experiment, the difference was determined between the values of XYZ coordinates obtained by means of the EGNOS solution and the catalog values of the reference station coordinates coming from the RINEX file header. Difference values for the coordinates of individual reference stations were determined on the basis of the relationship:

$$\begin{cases} DX = X_{EGNOS} - X_{RINEX} \\ DY = Y_{EGNOS} - Y_{RINEX} \\ DZ = Z_{EGNOS} - Z_{RINEX} \end{cases} \quad (3)$$

where:

(DX, DY, DZ) - difference of coordinate values;

$(X_{EGNOS}, Y_{EGNOS}, Z_{EGNOS})$ - coordinates of the reference station determined after the application of the EGNOS differential corrections received from satellites S120, S124, and S126;

$(X_{RINEX}, Y_{RINEX}, Z_{RINEX})$ -catalog values of the coordinates for each reference station on the basis of the RINEX file.

Figures 2,3,4 present the values of the DX, DY, and DZ parameters obtained for the REF1 reference station. The mean value of the DX parameter for the REF1 station (Fig.2) is approximately -2.7 m (after the S126 correction) and -3.7 m (after the S120 and S124 corrections). When the differential correction received from satellite S126 was applied, there was a large dispersion of results, which is reflected in the precision of determining the DX parameter.

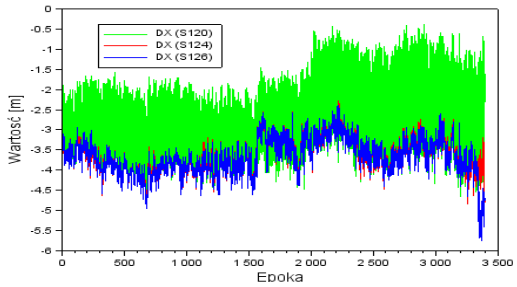

Fig. 2. The difference between the X coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the REF1 station.

The mean value of the DY parameter for the REF1 station (Fig.3) is approximately 0.1 m (after the S126 correction) and 0.5 m (after the S120 and S124 correction). The dispersion of the parameter DY results after the S126 correction is greater than that obtained after the S120 and S124 corrections.

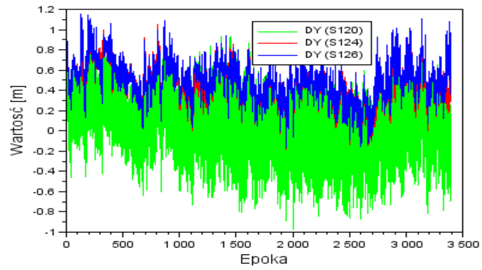

Fig. 3. The difference between the Y coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the REF1 station.

The mean value of the DZ parameter for the REF1 station (Fig.4) is approximately -2.1 m (after the S126 correction) and -2.7 m (after the S120 and S124 correction). It is worth noting that the lowest differences of the coordinate values obtained by means of the EGNOS solution and the catalog values coming from the RINEX file may be observed for the Y and the greatest for the X coordinate.

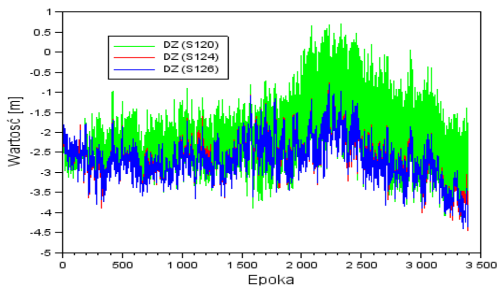

Fig. 4. The difference between the Z coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the REF1 station.

Figures 5,6,7 present the values of the DX, DY, and DZ parameters obtained for the VirA reference station.

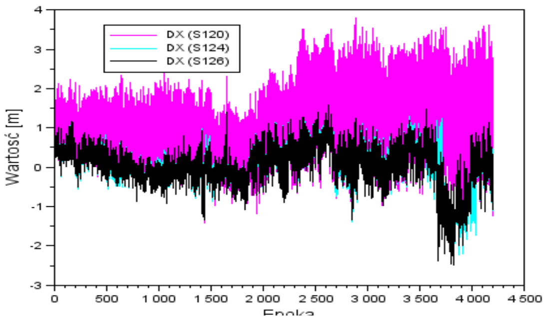

Fig. 5. The difference between the X coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirA station.

The mean value of the DX parameter for the VirA station (Fig.5) is approximately 1 m (after the S126 correction) and 0.1 m (after the S120 and S124 corrections). The dispersion of the values obtained for the DX parameter varies from -2.5 m to almost 4 m. The mean value of the DY parameter for the VirA station (Fig.6) is approximately -0.6 m (after the S126 correction) and -0.1 m (after the S120 and S124 corrections).

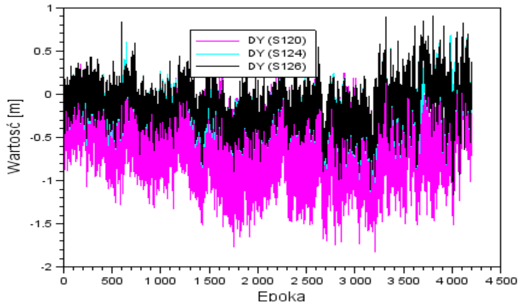

Fig. 6. The difference between the Y coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirA station.

The mean value of the DZ parameter for the VirA station (see Fig.7) is approximately -0.6 m (after the S126 correction) and -1.1 m (after the S120 and S124 corrections).

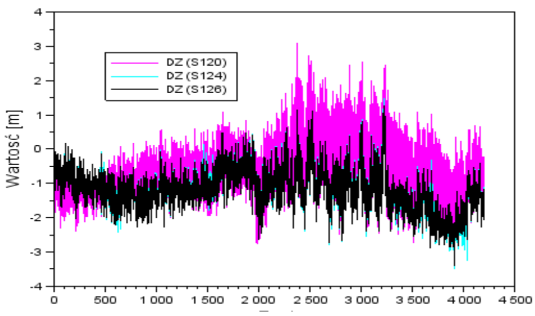

Fig. 7. The difference between the Z coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirA station.

For the VirA station, the lowest differences of the coordinate values obtained by means of the EGNOS solution and the catalog values coming from the RINEX file may be observed for the Y and the greatest for the Z coordinate. Figures 8,9,10 present the values of the DX, DY, and DZ parameters obtained for the VirB reference station. The mean value of the DX parameter for the VirB station (Fig.8) is approximately 1 m (after the S126 correction) and 0.1 m (after the S120 and S124 correction).

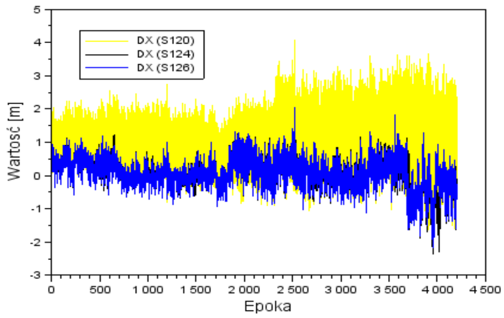

Fig. 8. The difference between the X coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirB station.

The mean value of the DY parameter for the VirB station (see Fig.9) is approximately -0.5 m (after the S126 correction) and -0.1 m (after the S120 and S124 corrections).

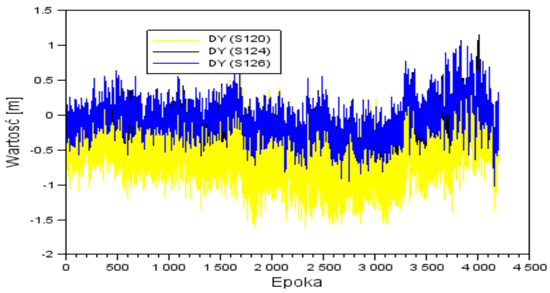

Fig. 9. The difference between the Y coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirB station.

The dispersion of the values obtained for the DX parameter varies from -2 m to almost 4 m. The mean value of the DY parameter for the VirB station (Fig.10) is approximately -0.6 m (after the S126 correction) and -1.1 m (after the S120 and S124 corrections). For the VirB station, the lowest differences of the coordinate values obtained by means of the EGNOS solution and the catalog values coming from the RINEX file may be observed for the Y and the greatest for the Z coordinate. It should be added that the nature of the changes in the values of the DX, DY and DZ parameters is very similar for stations VirB and VirA.

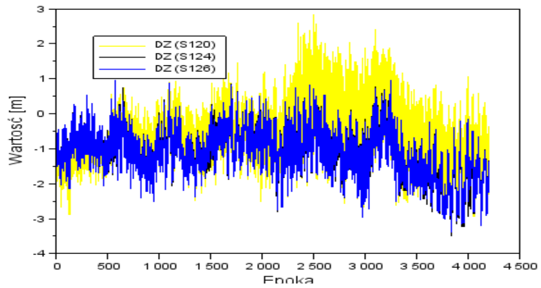

Fig. 10. The difference between the Z coordinate value obtained by means of the EGNOS solution and the catalog values coming from the RINEX file for the VirB station.

IV. CONCLUSIONS

The article presents the preliminary results of determining the coordinates (and their accuracy) for 3 reference stations (REF1, Vira and virB) after using EGNOS differential correction. The experiment was conducted in the Dęblin airport area. Three GNSS receivers were used in the experiment i.e. one Topcon Hiper TPS and two TRIMBLE NETRS receivers. In the research test, the coordinates of a particular reference station were determined using the SPP method for GPS observations and EGNOS differential corrections (received from the S120, S124, and S126 satellites). The following was determined on the basis of the tests conducted:

- the mean accuracy of the XYZ coordinate determination for each base station is below 2 m;

- Mean Radial Spherical Error (Mp) for each base station does not exceed 3 m;

- EGNOS differential correction received from the S126 satellite allows the achievement of lesser mean positioning errors than those obtained from S120 and S124;

-for the REF1 station, the lowest differences between the coordinate values obtained by means of the EGNOS solution and the catalog values coming from the RINEX file may be observed for the Y (mean difference below 0.5 m) and the greatest for the Z coordinate (mean difference better than -3.7 m).

-for the VirA and VirB reference stations, the lowest differences between the coordinate values obtained by means of the EGNOS solution and the catalog values coming from the RINEX file may be observed for the Y (mean difference below -0.5 m) and the greatest for the Z coordinate (mean difference better than -1.1 m).

-the use of EGNOS correction received from the S126 satellite increases the dispersion of the DX, DY and DZ results obtained for each base station, in comparison with the results obtained using differential corrections received from the S120 and S124.

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