GEODEZJA I KARTOGRAFIA
GEODESY AND CARTOGRAPHY
Vol. 54, No 2, 2005, pp. 81-92

Static code DGPS positioning based on three reference stations

Mieczysław Bakuła

University of Warmia and Mazury
Chair of Satellite Geodesy and Navigation
5 Heweliusza St., 10-957 Olsztyn, Poland
e-mail: mbakula@uni.olsztyn.pl

Received: 15 April 2005/Accepted: 18 July 2005

Abstract: The use of a network of reference stations instead of a single reference station allows to model some systematic errors in a region, and to increase the operational distance between the rover and reference stations. Permanent GPS reference stations exist in many countries, and GPS observations are available for the users in real-time mode and in post-processing. The paper presents DGPS post-processing positioning with the use of three reference stations. The traditional DGPS technique is based on one reference station. It has been shown that the accuracy of such positioning is about 1–2 meters, depending on the number of satellites being tracked and the resulting value of PDOP (Position Dilution of Precision). The accuracy of DGPS positioning degrades when the distance between the rover and the base station increases. The paper shows that when three reference stations are used simultaneously, pseudorange corrections for a virtual reference station, located in the vicinity of an unknown station can be created, and distribution of pseudorange corrections over time can be analysed and modelled. Three reference stations give redundant observations and enable to reduce some measurement errors and biases. Practical calculations and analysis of accuracy have been presented for medium-long and long distances between the rover and reference stations.

Keywords: DGPS, pseudorange corrections, multiple reference stations

---

1. Introduction

The concept of using a multiple reference station network for GPS positioning has been investigated by several research groups over the last years. A review of various multi-reference station network approaches can be found in Fotopoulos and Cannon (2001) and in other original papers (e.g. Wanninger, 1995; Wübbena et al., 1996; Wanninger, 1997; Raquet, 1997; Lachapelle et al., 2000; Landau et al., 2002; Euler et al., 2001; Kashani et al., 2004). The models presented in those studies concern mostly the use of carrier-phase observable when high accuracy (cm or mm) is expected. To achieve that, the ambiguity should first be resolved. However, in the case of DGPS technique there is no need to resolve ambiguities since only code observables are applied. Traditional DGPS positioning, based on the Coarse Acquisition (C/A) code, is a technique where at least two receivers are used. One GPS receiver is located at a reference site with known coordinates, and the other receiver is usually roving freely or is placed at an unknown point. The reference station calculates pseudorange corrections (PRC) that are applied to the roving receiver in near real time (real-time DGPS) or after the survey (post-processing DGPS). In order to provide differential positioning service at a large area, several reference stations must be used (Wanninger, 2003). The role of multiple reference stations for the improvement of the DGPS accuracy was discussed in view of DGPS system using STARFIX geostationary satellite based data link (Lapucha and Huff, 1992). The approach of multiple reference stations network is known as wide-area DGPS (WADGPS), for example WAAS (Wide Area Augmentation System) or EGNOS (European Geostationary Navigation Overlay Service). Practical tests with WAAS and EGNOS systems presented by Chen and Li (2004) show that it is possible to achieve the accuracy of 1–2 m in the horizontal components and 2–4 m in the vertical components at the confidence level of 95%. The use of a virtual DGPS solution slightly improved standard solutions of WAAS/EGNOS systems. The tests were performed with a handheld DGPS receiver – Garmin12.

Traditional DGPS positioning approach was studied in many papers worldwide. Practical tests show that the accuracy of code differential positioning is within 1–2 m and sometimes even better. Due to the degradation of standard DGPS positioning by distance-dependent errors, this paper presents the approach of linear interpolation, and additionally – the smoothing process of pseudorange corrections in order to obtain better accuracy of the positions determined. The calculations presented in the paper are based on data from Ashtech μZ-CGRS, state-of-the-art, low noise, 12-channel GPS receiver.

It should also be pointed out that the accuracy of code DGPS positioning depends on the quality of code measurements that is specific for a GPS hardware and software. It means that using different GPS equipment one can expect different accuracy of DGPS positioning.

2. Observation equation of pseudorange measurements

The pseudorange equation corresponds to the geometric distance that would be travelled by the signal in the propagation medium, i.e. in a vacuum where there are no clock errors or other biases. Taking those errors and biases into account, the complete expression for the pseudorange takes the form (Teunissen and Kleusberg, 1996):

$$P_i^k(t) = \rho_i^k(t) + c[\delta_i(t) - \delta^k(t)] + I_i^k + T_i^k + d^{eph} + d_i(t) + d^k(t) + m_i(t) + \varepsilon_i^k \quad (1)$$

where: $\rho_i^k(t)$ – geometric range between the satellite k (at signal transmission time) and the receiver i (at signal reception time), computed from ephemeris data and station coordinates; $\delta_i(t)$ – receiver clock error; $\delta^k(t)$ – satellite clock error; I_i^k – effect of delay due to the ionosphere; T_i^k – effect of delay due to the troposphere; d^{eph} – effect of ephemeris error; $d_i(t)$ – effect of receiver hardware delay; $d^k(t)$ – effect of satellite hardware delay; $m_i(t)$ – effect of multipath; ε_i^k – pseudorange measurement error.

The right-hand side of (1) can be written in another way (Raquet, 1999):

$$P_i^k(t) = \rho_i^k(t) + \Delta\delta_I + \Delta\delta_{II} + \Delta\delta_{III} + \varepsilon_i^k \quad (2)$$

The first term, $\Delta\delta_I$, of (2) includes errors that are cancelled in DGPS positioning, i.e. clock offsets, atmospheric delay and satellite hardware delay. The term $\Delta\delta_{II}$ is a correlated error term and it includes all errors that are a function of the receiver position. They are called correlated errors because they are correlated between receivers that are close to each other. The correlated errors include the ionospheric error, the tropospheric error and satellite ephemeris errors. The third term, $\Delta\delta_{III}$, includes all errors that are not cancelled in the process of generating pseudorange corrections, and which are not a function of the receiver position. That is why they are uncorrelated. The uncorrelated errors include the multipath, receiver hardware delay and measurement noise. In order to reduce the influence of correlated and partly uncorrelated errors, linear interpolation of pseudorange corrections, calculated with the use of three reference stations was applied in the study.

3. Pseudorange corrections for a virtual reference station

In order to reduce the magnitudes of distance-dependent errors, a virtual reference station can be used with virtual pseudorange corrections calculated using linear interpolation, based on three reference stations. Additionally, smoothing of pseudorange corrections for each satellite can be applied in order to reduce some non-systematic errors. The flowchart of that process is shown in Fig. 1.

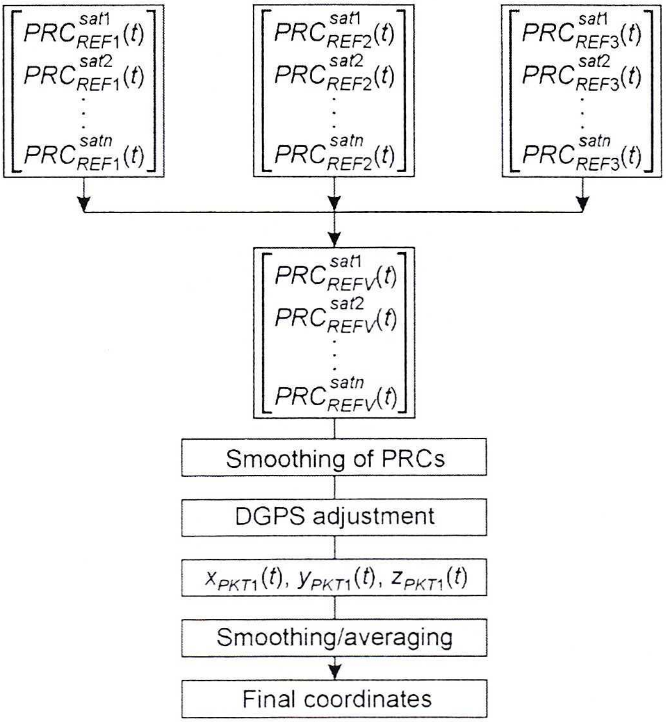

Fig. 1. Flowchart of the strategy used in differential GPS positioning based on three reference stations

Three pseudorange corrections generate a correlation plane for each satellite. The pseudorange correction for each satellite can thus be presented as follows:

$$a(t)x_{REF1} + b(t)y_{REF1} + c(t) = PRC_{REF1}(t) \tag{3a}$$

$$a(t)x_{REF2} + b(t)y_{REF2} + c(t) = PRC_{REF2}(t) \tag{3b}$$

$$a(t)x_{REF3} + b(t)y_{REF3} + c(t) = PRC_{REF3}(t) \tag{3c}$$

The factors $a(t)$, $b(t)$, $c(t)$ are calculated for every epoch according to the matrix equation:

$$\begin{bmatrix} a(t) \\ b(t) \\ c(t) \end{bmatrix} = \begin{bmatrix} x_{REF1} & y_{REF1} & 1 \\ x_{REF2} & y_{REF2} & 1 \\ x_{REF3} & y_{REF3} & 1 \end{bmatrix}^{-1} \begin{bmatrix} PRC_{REF1}(t) \\ PRC_{REF2}(t) \\ PRC_{REF3}(t) \end{bmatrix} \tag{4}$$

where x_{REF}, y_{REF} are planar coordinates of reference stations.

An example of pseudorange corrections for one satellite at the reference stations of ASG-PL network, located in the area of a range up to 300 km is shown in Fig. 2.

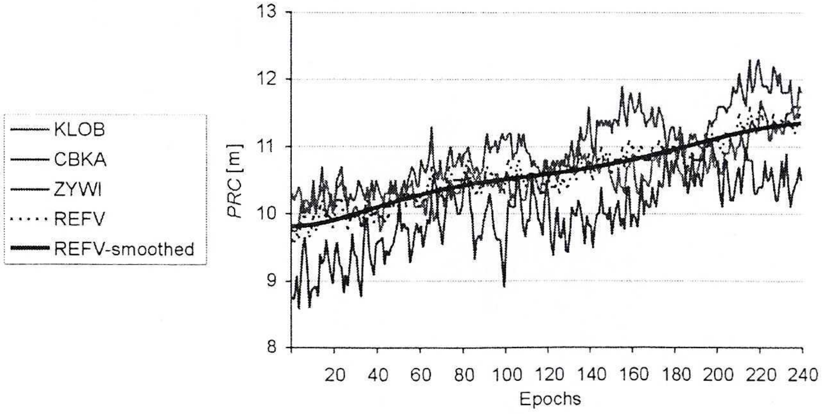

Fig. 2. Magnitudes of pseudorange corrections at KLOB, ZYWI, CBKA reference stations, and at a virtual reference station (in the vicinity of the LELO station) for the SV 11, in the time span from 13:00 to 13:20 GMT, 17 March 2005

Figure 2 illustrates pseudorange corrections: PRC_{KLOB}, PRC_{CBKA} and PRC_{ZYWI} for one satellite obtained at KLOB, CBKA and ZYWI reference stations, as well as the pseudorange corrections for the virtual reference station, calculated according to (3) and (4). Pseudorange corrections of the virtual reference station were linearly interpolated (PRC_{REFV}) and additionally smoothed ($PRC_{REFV}^{smoothed}$).

4. Adjustment of DGPS observations

In order to determine the coordinates of an unknown point in the global geocentric coordinate system, the observation equation must be linearized (Leick, 1995; Parkinson and Spilker, 1996; Hofmann-Wellenhof et al., 1997). The linearization process is carried out for each of the observed satellite. Let us denote by **L** the vector of observations, by **X** the vector of unknowns and by **A** the design matrix. Then, employing the least-squares method, the estimator of the unknown vector $\hat{\mathbf{X}}$ equals:

$$\hat{\mathbf{X}} = (\mathbf{A}^T \mathbf{P} \mathbf{A})^{-1} \mathbf{A}^T \mathbf{P} \mathbf{L} \tag{5}$$

where **P** is a weight matrix.

It is well known that the values of $\hat{\mathbf{X}}$ depend on both functional and stochastic models. In the presented DGPS post-processing positioning based on the least-squares solution, the matrices of (5) are as follows:

$$\mathbf{A} = \begin{bmatrix} -\dfrac{x^1(t) - x_{i0}}{\rho_{i0}^1(t)} & -\dfrac{y^1(t) - y_{i0}}{\rho_{i0}^1(t)} & -\dfrac{z^1(t) - z_{i0}}{\rho_{i0}^1(t)} \\ \vdots & \vdots & \vdots \\ -\dfrac{x^n(t) - x_{i0}}{\rho_{i0}^n(t)} & -\dfrac{y^n(t) - y_{i0}}{\rho_{i0}^n(t)} & -\dfrac{z^n(t) - z_{i0}}{\rho_{i0}^n(t)} \end{bmatrix} \tag{6}$$

$$\mathbf{L} = \begin{bmatrix} P_i^1(t) - \rho_{i0}^1 + \Delta\delta t^1 + PRC_{REFV}^{sat1}(t) \\ \vdots \\ P_i^n(t) - \rho_{i0}^n + \Delta\delta t^n + PRC_{REFV}^{satn}(t) \end{bmatrix} \tag{7}$$

$$\mathbf{P} = \mathbf{I} \tag{8}$$

where $PRC_{REFV}^{sati}(t)$ $(i = 1, 2, ..., n)$ represents pseudorange corrections for the virtual reference station, x_{i0}, y_{i0}, z_{i0} are the approximate coordinates for the unknown station, $x^k(t)$, $y^k(t)$, $z^k(t)$ are the coordinates of the satellite k, and

$$\rho_{i0}^k(t) = \sqrt{[x^k(t) - x_{i0}]^2 + [y^k(t) - y_{i0}]^2 + [z^k(t) - z_{i0}]^2} \tag{9}$$

Additionally, the values of $PRC_{REFV}^{sati}(t)$ were smoothed by the *supsmooth* function of Mathcad 11 software. The *supsmooth* function uses a linear least-squares fitting procedure for a symmetric k nearest neighbouring data to make a series of line segments through the data. It adaptively chooses different bandwidths for different portions of the data. The *supsmooth* function was also implemented to smooth the coordinates obtained from (5).

In the presented DGPS positioning approach a unit weight matrix was used (8), following the assumption that the accuracy of pseudorange measurements obtained from individual satellites is the same. However, when multipath affects pseudorange measurements, the presented model will not eliminate the effect of gross errors.

5. Numerical examples

The GPS data used in this chapter were collected at seven permanent reference stations of the ASG-PL (e.g. Polish Active Geodetic Network) network (Fig. 3): KLOB in Kłobuck, KATO in Katowice, WODZ in Wodzisław Śląski, TARG in Tarnowskie Góry, ZYWI in Żywiec, LELO in Lelów and CBKA in Warsaw, Poland, in 17 April 2005, from 13:00 to 13.20 UTC with 5 s sampling interval; during the measurements PDOP was between two and four. Six satellites were used in the calculations. The reference stations are equipped with Ashtech μZ-CGRS (Continuous Geodetic Reference Station) receivers and ASH701945C_M SNOW antennas, except the stations CBKA where another type of the antenna is used, i.e. ASH701945E_M SNOW (Kryński et al, 2003).

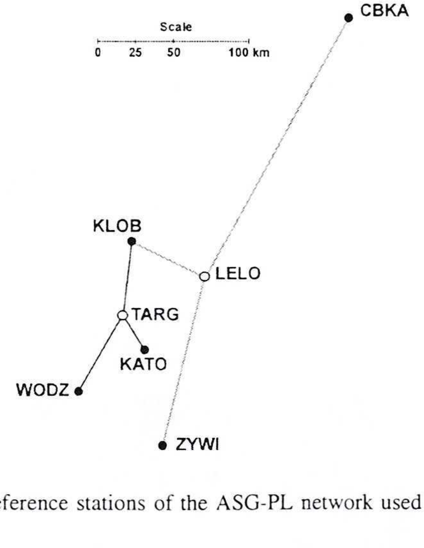

Fig. 3. Permanent reference stations of the ASG-PL network used in calculations

Two cases were considered:

1) distances between reference stations up to about 100 km; reference stations: KLOB, KATO, WODZ and the rover station TARG,
2) distances between reference stations up to about 300 km; reference stations: KLOB, CBKA, ZYWI and the rover station LELO.

In both cases, the calculations were performed as in traditional DGPS positioning where one reference station is used; results for shorter distances are shown in Fig. 4, and for longer distances in Fig. 6. Further, calculations were performed with the use of three reference stations. The results are presented in Fig. 5 and Fig. 7, respectively. In all approaches, "real errors" (dx, dy, dz) were calculated as differences between the fixed coordinates of the rover stations (TARG, LELO) and the coordinates obtained in successive epochs of differential positioning.

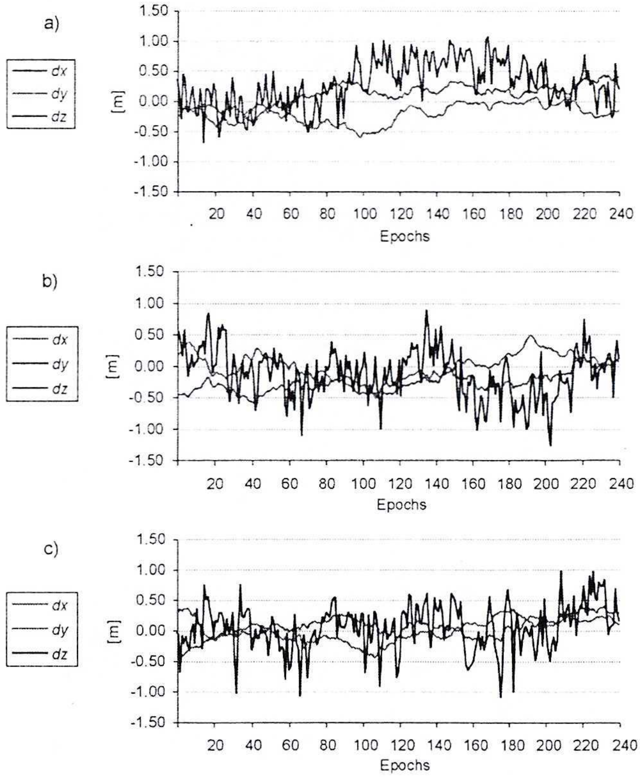

Fig. 4. Real horizontal (*dx*, *dy*) and vertical (*dz*) errors of traditional DGPS positioning obtained in the local topocentric coordinate system for TARG station: a) WODZ-TARG (58 km), b) KLOB-TARG (51 km), c) KATO-TARG (25 km)

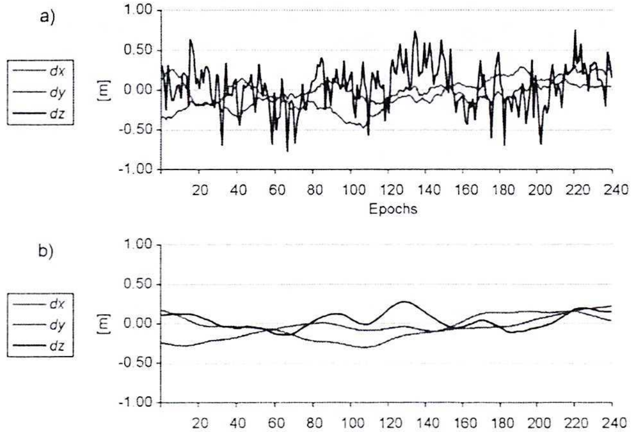

Fig. 5. Real horizontal (*dx*, *dy*) and vertical (*dz*) errors of differential GPS positioning, obtained in the local topocentric coordinate system when three reference stations: WODZ, KLOB and KATO were used; with the linear interpolation and without smoothing of final coordinates (Fig. 5a), and with smoothing (Fig. 5b)

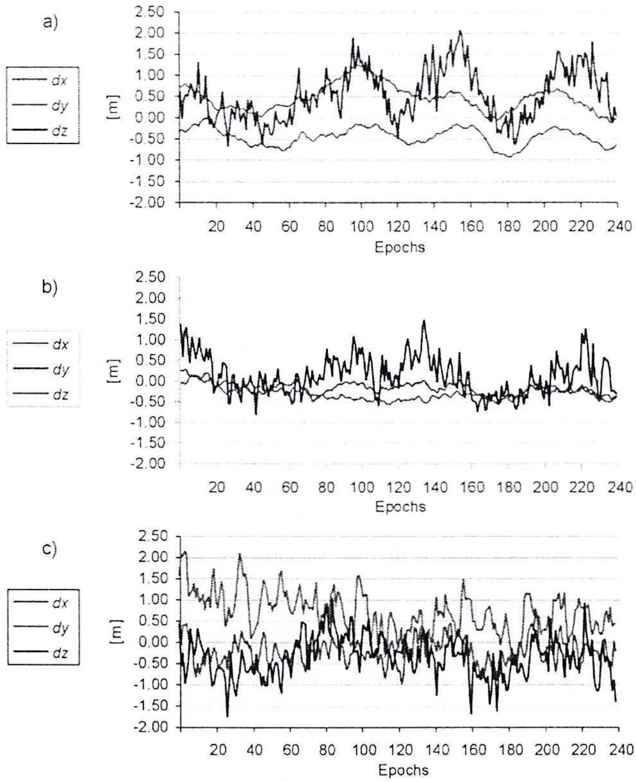

Fig. 6. Real horizontal (*dx*, *dy*) and vertical (*dz*) errors of traditional DGPS positioning obtained in the local topocentric coordinate system for LELO station: a) ZYWI-LELO (115 km), b) KLOB-LELO (55 km), c) CBKA-LELO (198 km)

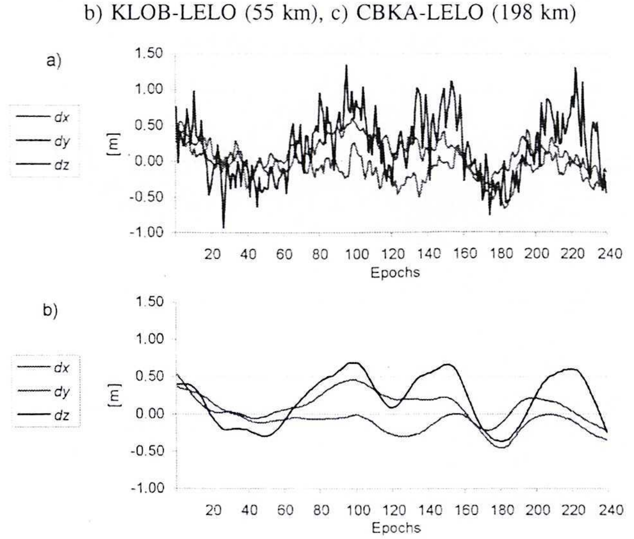

Fig. 7. Real horizontal (*dx*, *dy*) and vertical (*dz*) errors of differential GPS positioning, obtained in the local topocentric coordinate system, when three reference stations: WODZ, CBKA and ZYWI were used; with the linear interpolation and without smoothing of final coordinates (Fig. 7a), and with the smoothing process (Fig. 7b)

For the first case (distances up to 100 km) the arithmetic mean (Δx, Δy, Δz) of differences between the coordinates determined and the respective fixed ones as well as standard deviations σ of final coordinates were calculated (Table 1):

Table 1.

Ref. station	Δx	σ_x	Δy	σ_y	Δz	σ_z
WODZ	-0.20	0.16	0.12	0.18	0.29	0.38
KLOB	-0.01	0.21	-0.26	0.16	-0.12	0.40
KATO	0.03	0.19	0.06	0.17	0.06	0.39
All 3 stations	-0.03	0.15	-0.05	0.12	0.04	0.10

Similarly, for the second case (distances up to 300 km) the arithmetic mean (Δx, Δy, Δz) of differences between the coordinates determined and the respective fixed ones as well as standard deviations of final coordinates were calculated (Table 2):

Table 2.

Ref. station	Δx	σ_x	Δy	σ_y	Δz	σ_z
WODZ	-0.45	0.21	0.47	0.32	0.55	0.61
KLOB	-0.26	0.16	-0.20	0.21	0.07	0.93
KATO	0.70	0.51	-0.23	0.31	-0.35	0.49
All 3 stations	-0.09	0.16	0.12	0.17	0.20	0.33

Comparing two cases where different distances between the reference stations and the rover were used, it is clear that in the first case (shorter distances) – the standard deviations of determined coordinates of the rover were within the range of 0.10 – 0.15 m, but true errors were within the range of – 0.05 to 0.04 m. In the final calculations of the presented strategy, "real errors" were smaller than standard deviations. It is very useful from a practical point of view, but in the case of independent reference stations, there were two cases where values of real errors were larger than standard deviations, i.e.

- WODZ-TARG:

  $\Delta x = -0.20$ m with standard deviation of 0.16 m,
- KLOB-TARG:

  $\Delta y = -0.26$ m with standard deviation of 0.16 m.

In the case where distances between the reference stations and rover were longer, standard deviations of final calculations were within the range of 0.12 – 0.33 m but true errors were within the range of – 0.09 to 0.20 m. Note that the real errors are also below the values of standard deviations, as for shorter distances. But in the case of independent reference stations, there were also a few cases where real errors were larger than standard deviations, i.e.

- ZYWI-LELO:

  $\Delta x = -0.45$ m with standard deviation of 0.21 m,

  $\Delta y = 0.47$ m with standard deviation of 0.32 m,
- KLOB-LELO:

  $\Delta x = -0.26$ m with standard deviation of 0.16 m,
- CBKA-LELO:

  $\Delta x = 0.70$ m with standard deviation of 0.51 m.

The numerical experiments performed show that in the standard approach of DGPS positioning the estimated accuracy is not reliable; it frequently is overestimated. When three reference stations were used, in both cases the real errors of coordinates determined were smaller than standard deviations. It should also be pointed out that the real errors of final coordinates were larger for longer distances, probably due to the non-linear behaviour of correlated errors. The averaging process used in the final stage can be also quite helpful in obtaining better accuracy by reducing some white noise errors.

6. Conclusions

In this paper, the linear interpolation approach was applied to generate pseudorange corrections of differential positioning with the use of the C/A code. Additionally, the smoothing process of pseudorange corrections and final coordinates was applied in order to reduce some non-systematic errors. Finally, averaging of coordinates was implemented. Test data from the ASG-PL network was used to evaluate the performance of this method. Each reference station is equipped with the state-of-the-art, low noise, 12-channel GPS receiver. The numerical results obtained show that the use of linear interpolation of pseudorange corrections could reduce distance-dependent errors in DGPS positioning. When the traditional method of DGPS positioning was applied, its accuracy differed depending on reference station used. The real accuracy of DGPS positioning for the shortest distance between the reference station and the rover, e.g. KATO – TARG, was within the range of 1 m, while for the longest distance (CBKA – LELO), it was within the range of 2 m. However, the application of the proposed method, with linear interpolation and a smoothing of pseudorange corrections, improved the accuracy of DGPS positioning to the range of 0.1–0.2 m for shorter distances and 0.2–0.5 m for the longer ones. For the shorter distances, the accuracy of final coordinates after averaging process was within a few centimetres, i.e. $\Delta x = -0.03$ m, $\Delta y = -0.05$ m and $\Delta z = 0.04$ m; for longer distances it was within the range of 0.1–0.2 m. However, for longer distances where more than three reference stations are available, the presented model should be further improved in order to reduce the effect of gross errors. If the reference stations are located within about 100 km, one can achieve a real accuracy below 0.2 m for every epoch observed. Such accuracy makes the method useful not only for navigation or any location-based service, but also for many mapping applications of the Geographic Information System.

Acknowledgments

The author would like to express his thanks to the anonymous reviewer and especially to Prof. Jan Kryński for their remarks and helpful suggestions. Data from ASG-PL reference stations used were kindly provided by the Head Office of Geodesy and Cartography, Poland and the Department of Geodesy and Cartography of the Silesian Voivodship.

References

Chen R., Li X., (2004): *Virtual Differential GPS Based on SBAS Signal*, GPS Solutions, Vol. 8, No 4, pp. 238-244.

Euler H.J., Keenan C.R., Zebhauser B.E., Wübbena G., (2001): *Study of Simplified Approach in Utilizing Information from Permanent Reference Station Arrays*, Paper presented at ION GPS 2001, Salt Lake City, Utah, pp. 379-391.

Fotopoulos G., Cannon M.E., (2001): *An Overview of Multi-Reference Station Methods for Cm-Level Positioning*, GPS Solutions, Vol. 4, No 3, pp. 1-10.

Hofmann-Wellenhof B., Lichtenegger H., Collins J., (1997): *Global Positioning System: Theory and Practice*, 4th ed., Springer, Berlin Heidelberg New York.

Kashani I., Grejner-Brzezińska D., Wielgosz P., (2004): *Towards Instantaneous Network-Based RTK GPS Over 100 km Distance*, Proceedings of the ION 60th Annual Meeting, 7-9 June, Dayton, Ohio, pp. 679-687.

Kryński J., Rogowski J.B., Zieliński J.B., (2003): *National Report of Poland to EUREF 2003*, Proceedigs of the Symposium of the IAG Subcommission for Europe (EUREF) held in Toledo, Spain, 4-7 June 2003, EUREF Publication No 13, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 33, Frankfurt am Main, pp. 264-268.

Lachapelle G., Alves P., Fortes L.P., Cannon M.E, Townsend B., (2000): *DGPS RTK Positioning Using a Reference Network*, Proceedings of GPS2000 (Session C3, Salt Lake City, 19-22 September), The Institute of Navigation, Alexandria, VA, pp. 1165-1171.

Lapucha D., Huff M., (1992): *Multi-Site Real-Time DGPS System Using Starfix Link; Operational Results*, Proceedings of the ION GPS-92 Meeting, 16-18 September Albuquerque, NM, pp. 581-588.

Landau H., Vollath U., Chen X., (2002): *Virtual Reference Stations Systems*, Journal of Global Positioning Systems, Vol. 1, No 2, pp. 137-143.

Leick A., (1995): *GPS Satellite Surveying*, 2nd ed., John Wiley & Sons, New York.

Parkinson B., Spilker J.J. (eds.), (1996): *GPS Theory and Applications*, Vol. 1 and Vol. 2, AIAA, Washington, DC.

Raquet, J., (1997): *A New Approach to GPS Carrier Phase Ambiguity Resolution Using a Reference Receiver Network*, Proceedings of National Technical Meeting, Santa Monica, 14-16 January, The Institute of Navigation, Alexandria, VA, pp. 357-366.

Raquet J., (1999): *Development of a Method for Kinematic GPS Carrier Phase Ambiguity Resolution Using Multiple Reference Receiver*, UCGE No 20116, (PhD thesis).

Teunissen P.J.G., Kleusberg A., (1996): *GPS Observation Equations and Positioning Concept*, GPS For Geodesy, Lecture Notes in Earth Sciences 60, (eds.) A. Kleusberg and P.J.G. Teunissen, Springer, Berlin Heidelberg New York, pp. 175-217.

Wanninger L., (1995): *Improved Ambiguity Resolution by Regional Differential Modelling of the Ionosphere*, Proceedings of the International Technical Meeting, ION GPS 95, Palm Springs, CA, pp. 55-62.

Wanninger L., (1997): *Real-Time Differential GPS-Error Modelling in Regional Reference Station Networks*, in F.K. Brunner (ed.), Advances in Positioning and Reference Frames, Proceedings of the IAG Scientific Assembly, Rio de Janeiro, Brazil, pp. 86-92.

Wanninger L., (2003): *GPS on the Web: Virtual reference stations (VRS)*, GPS Solutions, Vol. 7, No 2, pp. 143-144.

Wübbena G., Bagge A., Seeber G., Böder V., Hankemeier P., (1996): *Reducing Distance Dependent Errors for Real-Time Precise DGPS Applications by Establishing Reference Station Networks*, Proceedings of the International Technical Meeting, ION GPS 96, Kansas City, Missouri, pp. 1845-1852.

Statyczne kodowe pomiary DGPS z wykorzystaniem trzech stacji referencyjnych

Mieczysław Bakuła

Uniwersytet Warmińsko-Mazurski
Katedra Geodezji Satelitarnej i Nawigacji
ul. Heweliusza 5, 10-957 Olsztyn
e-mail: mbakula@uni.olsztyn.pl

Streszczenie

Wykorzystanie sieci stacji referencyjnych zamiast pojedynczej stacji referencyjnej w pozycjonowaniu DGPS umożliwia modelowanie poprawek różnicowych dla dowolnej pozycji. W tradycyjnej metodzie DGPS wykorzystuje się tylko jedną stację referencyjną, co powoduje degradację dokładności pozycji przy zwiększaniu odległości od tej stacji. W przypadku obserwacji nadliczbowych z dodatkowych stacji referencyjnych można wygenerować korekcje do pseudoodległości dla wirtualnej stacji referencyjnej, zlokalizowanej w pobliżu wyznaczanego punktu. W pracy przedstawiono zastosowanie liniowej interpolacji do generowania korekcji do pseudoodległości dla wirtualnej stacji referencyjnej i jej wpływ na dokładność wyznaczanych pozycji. Dodatkowo zastosowano procedury wygładzania korekcji. Testy numeryczne przedstawiono z wykorzystaniem permanentnych stacji referencyjnych sieci ASG-PL, przy wykorzystaniu odbiorników Ashtech μZ-CGRS. W przypadku wykorzystania tylko jednej stacji referencyjnej odchyłki wyznaczonych pozycji DGPS od wielkości rzeczywistych były w granicach 1–2 m, natomiast w przypadku zastosowania trzech stacji referencyjnych oraz przedstawionej metodyki obliczeń dla sesji statycznej otrzymano pozycje z dokładnością rzędu 0.1–0.2 m.