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Section: Technologies of Geodesy and Cadastre

New On-line System for Automatic Postprocessing of Fast-static and Kinematic GNSS Data

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Abstract

The paper presents principles and performance of new on-line automatic system for GNSS data post-processing developed at the University of Warmia and Mazury in Olsztyn. The system allows for obtaining a precise position of the user receiver on the basis of fast-static and kinematic GNSS data. The system requires minimal user input. The user uploads RINEX data files collected with a GNSS receiver, the system carries-out all data processing, and the user gets back resulting coordinates via email. The internal software operates in static, ultra-fast-static and kinematic modes. The developed algorithms support combined processing of multi-GNSS (GPS+Galileo) and multi-frequency observations in a single mathematical model. The solution is obtained with respect to three neighboring GNSS reference stations (multistation solution) and takes advantage of precise tropospheric and ionospheric corrections. The system offers centimeter-level accuracy with baselines lengths of up to 100 kilometers.

Keywords: Global Positioning System (GPS); Global Navigation Satellite System (GNSS); precise satellite positioning; automatic GNSS post-processing software.

1. Introduction

In recent years, the international scientific community carried out important number of studies on the development of algorithms based on the precise satellite positioning. Majority of these studies concerns the precise determination of the position on the basis of long static GPS sessions used for geodynamic studies as well as for preserving international terrestrial coordinate systems in geodesy [1]. The developed software packages,for example Bernese, GAMIT/Globk, PAGES, GIPSY,allow for obtaining high accuracy determinations of coordinates of sites that predispose them to use for of geodetic, geodynamic and engineering purposes. These programs allow for the post-processing of baselines connecting the stations with GPS receivers with lengths of up to several hundred or even over a thousand kilometers [2]. However, the conditioning factor to obtain high accuracy of the solution is to conduct long observation sessions which allows for the correct solution of carrier phase ambiguity. What is more, these packages are highly sophisticated and thus the broad knowledge in the field of GNSS data post-processing is required. These software packages are used not only to estimate the coordinates of the sites, but also to model the additional parameters such as precise orbits and clocks of satellites, receiver antenna phase center offsets and the parameters characterizing of the ionosphere and troposphere. Although primarily designed for geodynamic studies, these software are frequently the basis for the automatic systems of GPS data post processing [3, 4].

On the other hand commercial software packages (e.g., Ashtech GNSS Solutions, Topcon Tools, Javad Justin, etc.), which enable to process data from short sessions also have their limitations. These systems mostly do not operate in a network solution, but in a single baseline mode. Hence these software packages do not take into account mathematical correlations between the GPS observations. Another drawback of the existing, commercial software is that these programs do not use highly efficient algorithms for the elimination of ionospheric or tropospheric refraction, which greatly limits their capabilities. Significant decorrelation of ionospheric delay occurs when long baselines are processed. Since ionospheric delays and ambiguities are highly correlated, the correct solution of the carrier phase ambiguities is very difficult. For these reasons these software packages are designed primarily to process short and medium baselines and require relatively long data spans.

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Alternative to the mentioned above commercial and scientific post-processing software presentautomatic GNSS post processing systems. These systems require minimal user input and knowledge in the field of GNSS data post-processing.Several systems has been yet developed. Many of these, like Canadian CSRS-PPP [5], US APPS [6], GAPS developed at UNB [7] andmagicGNSS developed by GMV [8] operate worldwide. On the other hand, these systems rely on the Precise Point Positioning (PPP) approach. PPP method has few limitations and drawbacks, the main are lower accuracy and longer convergence time in relation to the relative positioning method [9, 10]. There are also automatic post processing systems which operate in relative positioning mode, however these are related to particularpermanent networks and thus operate locally or regionally [11]. One of these systems is Polish POZGEO offered by the ASG-EUPOS national network [12], however this software does not process both short sessions and kinematic data.

Due to limitations of the existing post-processing software, an effort was put in order to develop a new automatic system operating at the area of Poland. The new system presented in this paper has several advantages over existing software packages and automatic systems. The system is based on algorithms fromthe GINPOS scientific GNSS post-processing software developed at the University of Warmia and Mazury in Olsztyn [13].

The paper is organized as follows. Firstly, the functionality of the system as well as the methodology are described. Secondly, the performance of the static and kinematic post-processing with the use of the developed system is presented. Finally, the summary and conclusions are provided.

2. Concept and functionality of the system

Fast static and kinematic positioning require application of advanced and efficient methods for the ambiguity resolution. Time which is requiredfor the ambiguity resolution and validation (time-to-fix) is afunction of the length of observing session, distance between rover and reference receivers, number of tracked satellites, satellite and CORS network geometry as well as successful mitigation of atmospheric errors [14, 15]. Although the precise relative positioning has been widely used, still new approaches are developed in order to enhance reliability of the solution [16]. The developed software makes use of the newest scientific achievements in the field of precise positioning algorithms [13, 17], application of new GNSS signals (18–21] as well as of ionospheric and tropospheric delays modelling [22–26]. All of these lead to possibility of shortening required observing session with preservation and even advancemetin accuracy of user receiver coordinates determination.

The developed system is built of two main modules POZGEO-2 and NAWGEO-P, which allow for processing static and kinematic data, respectively. The solution is performed in multi-station mode (network) in reference to three closest stations from the ASG-EUPOS network [12]. The processed baseline lengthsmay reach even one hundred kilometers. The software requires only 5minutes of data with at least 10 s recording interval for static and 10-minute long sessions for kinematic mode. The accuracy of the final user coordinates are on the centimeter level, which was confirmed by a number of numerical experiments.

Figure 1 presents a brief scheme for GNSS data processing with the developed system. Access to the system is provided via *www* website where logged users upload their observational data in RINEXformat. In the next step, approximate position of the user receiver is obtained. This is carried outby absolute single point positioning approach with the use of the broadcast or precise orbits downloaded from the external servers. On the basis of the approximate position, the closest reference stations from ASG-EUPOS network are chosen and observing files from these stations are downloaded. Before the main modules of parameter estimation are executed, GNSS data preprocessing is performed. The main task of this step is to find and correct carrier phase cycle slips in both static and kinematic data.

Afterwards, the main modules of estimation of relative static/kinematic precise positioning model are executed. Only a brief description of the processing methodology is presented below. The main algorithms of the developed software are based on the relative geometry-based model, thus we make use of the double differenced (DD) carrier phase and pseudorange L1/L2 GPS data. However, the software is ready to apply new signals from GPS system (L5), as well as Galileo data (E1&E5a). In multi-GNSS approach a tightly combined solution is performed using L1/E1 & L5/E5a frequencies. More details about the developed methodology may be found in [21]. The solution is completed in three-step procedure. Firstly, a float solution is performed. In the next step integer carrierphase ambiguities are resolved and validated. Finally, the known ambiguities are introduced and fixed solution is obtained [13]. The LAMBDA method is applied to find the best DD integer ambiguity set [17]. The process of the ambiguity resolution (AR) is validated by both W-ratio and F-ratio tests [27]. The applied relative observational model is presented in Eq 1. For generalization, the equation is derived for applied frequency *n*.

$$\lambda_n \varphi_{kl,n}^{ij} - \varrho_{kl}^{ij} + T_{kl}^{ij} + I_{kl,n}^{ij} - \lambda_n N_{kl,n}^{ij} = 0$$

$$P_{kl,n}^{ij} - \varrho_{kl}^{ij} + T_{kl}^{ij} - I_{kl,n}^{ij} = 0 \quad (1)$$

where:

λ_n – carrier phase wavelength at n frequency; $\varphi^{ij}_{kl,n}$ – DD carrier phase observable for i, j satellites and k, l stations at n frequency; $P^{ij}_{kl,n}$ – DD pseudorange observable at n frequency; ϱ^{ij}_{kl} – DD geometric distance; $N^{ij}_{kl,n}$ – DD carrier phase ambiguities; T^{ij}_{kl} – DD tropospheric delay; $I^{ij}_{kl,n}$ – DD ionospheric delay at n frequency.

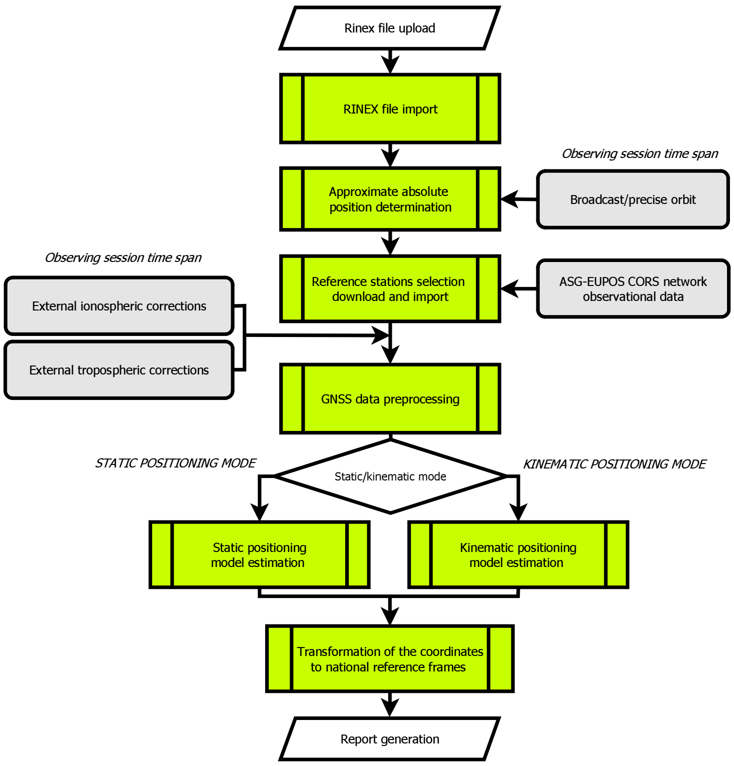

Fig. 1. Overall algorithm for GNSS data processing with the developed automatic system

The tropospheric and ionospheric delays are mitigated by introducing external network corrections from the ionospheric and tropospheric modelling modules connected with the system [25, 28]. The model parameters are estimated with use of the least squares estimation with a priori parameters constraining [21, 29].The final geocentric coordinates of the user receiver are converted to the national coordinate systems and finally a report is generated. The report contains final user coordinates with accuracy analysis, applied models, processing settings, observations quality check and parameters describing reliability of ambiguity resolution.

3. Numerical test

In this section the performance of the developed software and system is presented. The analysis is based on the accuracy and reliability analysis of the fast static and kinematic positioning.

3.1. Fast static positioning performance

The performance of the fast static positioning was evaluated on the basis of three test sites (PP03, PP02, RR04) inside the ASG-EUPOS network in Poland. The GPS dual-frequency static observation data were collected on July 18, 2012. The session lasted 8 hours starting at 5:30 UTC and ending at 13:30 UTC. Figure 2 shows user and reference stations used in the experiment. The baseline lengths varied from 30 to 85 km. The whole observing session was divided into 96 independent 5-minute long sessions with 5 s interval and 15° elevation mask.

Empirical ambiguity resolution and validation success rate (ASR) and ambiguity validation failure rate (AFR) served as the indicators of the reliability of AR process. ASR was defined as the ratio of sessions with correct AR over the total number of sessions. The ambiguity validation failure rate depicts the ratio of sessions with incorrectly resolved ambiguities which, however, passed the ambiguity validation process to the number of all sessions. The accuracy of the solutions was analyzed on the basis of repeatability of the coordinates (standard deviations of coordinates components *std*), as well as the mean coordinates residuals in respect to the reference coordinates of the user sites. The reference coordinates of the user receivers were obtained on the basis of post-processing of whole 8-hour long session.

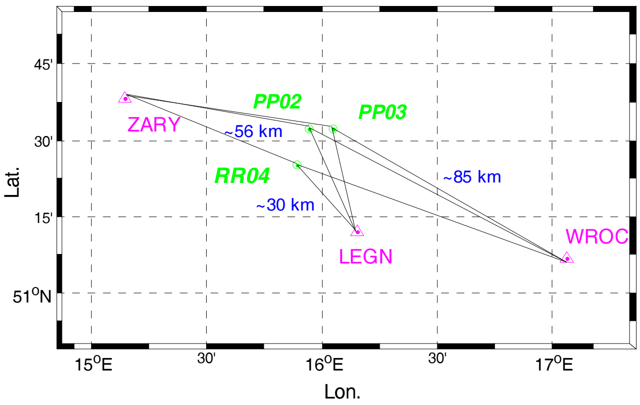

Fig. 2. Experimental network and baselines used in the rover solution

Statistics of the fast static positioning performance at the tested sites are shown in Table 1. The residuals of the coordinates obtained in each of 5-minute long sessions in respect to the reference position are illustrated in Fig. 3. As shown in Table 1, the ambiguity success rate varied from 92.7% to 99.0%, which can be regarded as high value. At the same time, the ambiguity validation failure was at the level of 0.0%. This indicates on the high reliability of the AR process and thus on the reliability of the final solution.

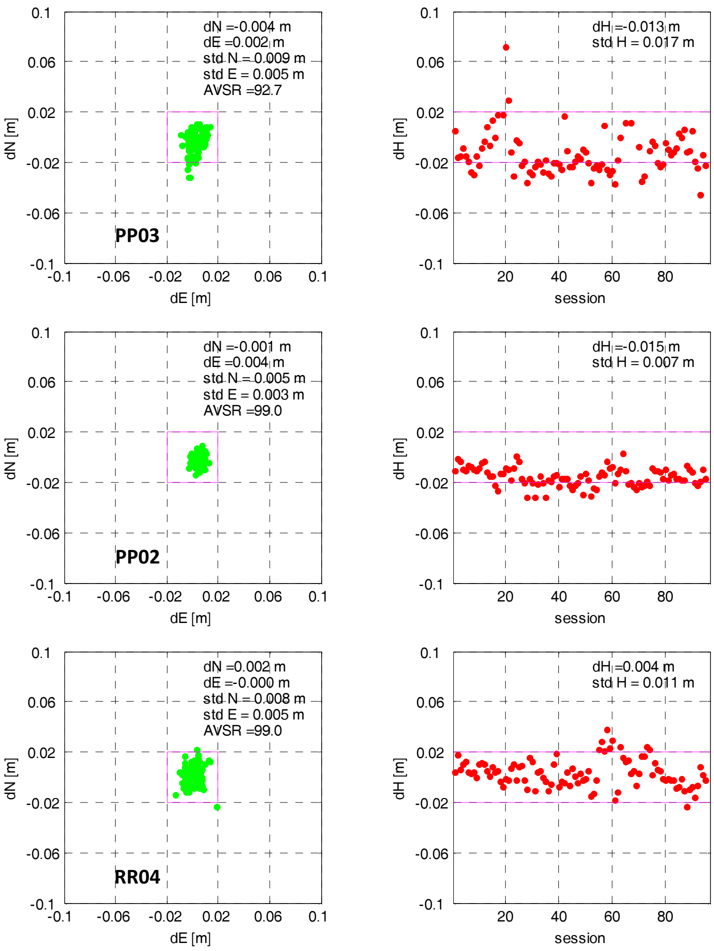

Fig. 3. Horizontal (left panel) and vertical (right panel) coordinate residuals of the tested sites PP03 (top), PP02 – middle, RR04 bottom

Table 1. Statistics of fast static positioning solution

Test site	N [cm]		E [cm]		U [cm]		ASR	AFR
	dN	sdt_N	dE	std_E	dU	std_U	[%]	[%]
PP03	–0.4	0.9	0.2	0.5	–1.3	1.7	92.7	0.0
PP02	–0.1	0.5	0.4	0.3	–1.5	0.7	99.0	0.0
RR04	0.2	0.8	0.0	0.5	0.4	1.1	99.0	0.0

The repeatability of the coordinates of each of the sites is on the sub-centimeter level. It can be seen from Fig. 3 that most of the coordinate residuals for each component is smaller than 2 cm. There are slight differences in repeatability of the position determination between the tested sites (Table 1). This may be caused by the differences in the observing conditions e.g. satellite visibility. The best results were obtained forthe PP02 site.

3.2. Kinematic positioning performance

In this section the performance of the new system for post processing of kinematic GNSS data is presented. The evaluation is based on the processing of GNSS data collected by the receiver in motion. The rover receiver was mounted on the helicopterused for laser scanning, thus its motion may be described as fast and highly dynamic. The observing session lasted 1 h (9:00–10:00) on 26.09.2012. The session was divided into two independent 30-minute long sessions with 1 s recording interval. During the session maximally 6 satellites were observed, thus the observing conditions may be regarded as harsh. The sessions were processed in the kinematic mode, actual coordinates of the user receiver were determined every second (epoch). The computations were performed in the multi-baseline solution in respect to three ASG-EUPOS permanent stations. The lengths of the baselines varied from 14 to 31 km (Fig. 4).

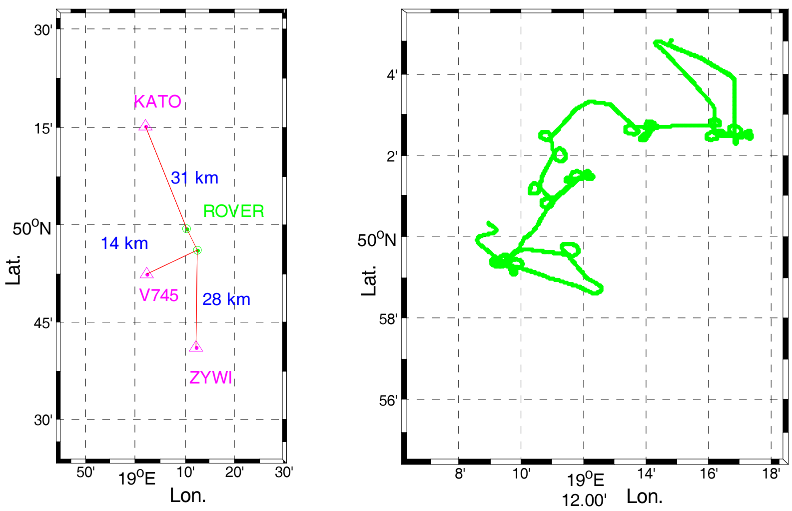

Fig. 4. Experimental network (left panel) and the trajectory of the rover receiver (right panel)

The solution obtained from the developed automatic system was compared to the solution from the commercial GNSS post processing software aided with the INS system, which served as the reference results.Coordinate differences of the rover receiver antenna of these two solutionswere compared and analyzed. In specific, standard deviation as well as the mean coordinate residuals were computed (Table 2, Fig. 5). The results confirms high agreement of the solutions. The standard deviations derived from the analyzed and reference solutions did not exceed 2 cm and 4 cm for the horizontal and vertical components, respectively (Table 2). Over 96% of the horizontal coordinate differences were smaller than 5 cm. The same indicator reached 55% for the height component. Higher height differences may be caused by different method for tropospheric delay modelling. In the developed system, network-derived tropospheric corrections were applied, at the same timethe applied commercial software is based on Saastamoinen model with standard atmospheric parameters, which approach may be regarded as less sensitive to changing tropospheric conditions.

Table 2. Statistics of the comparison of the kinematic solutions obtained from developed system and reference commercial software

	N	E	U
standard deviation [m]	0.02	0.01	0.04
mean difference [m]	–0.03	0.00	0.05
ratio of coordinate differences <5 cm [%]	96	100	55

The figure below presents histograms of the horizontal coordinate differences between two analyzed solutions (Fig. 4). It is clearly visible good agreement of the solutions. For the East component mean residual was about 0.00 m, at the same time for the N component can be observed a slight shift between solutions. Mean North residual reached –0.03 m (Table 1, Fig. 4). Summarizing on the basis of conducted numerical experiments, the developed system of post processing kinematic GNSS data indicates on a high consistency of the analyzed solutions.

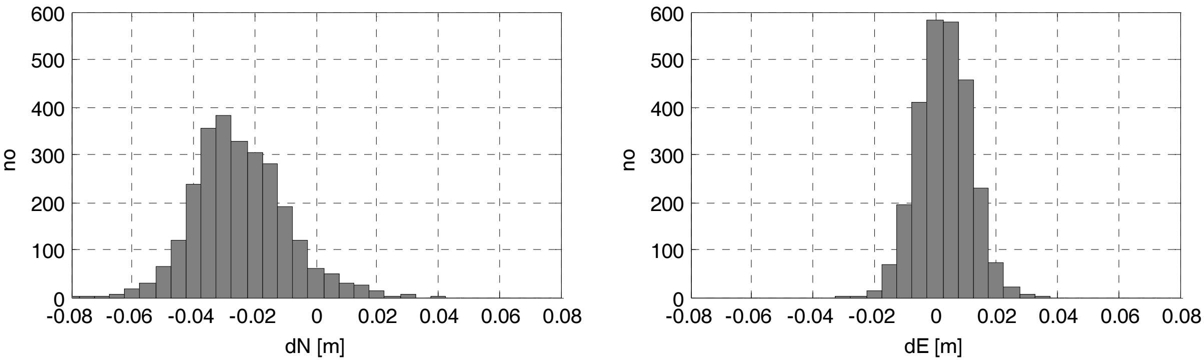

Fig. 5. Histograms of the horizontal coordinate differences obtained from the developed system and commercial reference solution

4. Summary and conclusions

The new on-line automatic system for post-processing GNSS data was developed. The algorithms allow for obtaining reliable precise position on the basis of fast static and kinematic GNSS data. The system is ready to use new GPS and Galileo signals. The algorithms use geometry-based model with the application of the Lambda method for ambiguity resolution. With the new system it is possible to obtain centimeter-level accuracy with only 5-minutes of GPS data, even at baselines of tens of kilometers within the ASG-EUPOS referencenetwork. The numerical experiments confirm high repeatability of the fast-static solution, as well as the good agreement of the kinematic solutions obtained from developed system and reference commercial software.

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