ANALIZA USPEŠNOSTI METODE PPP OB UPORABI STORITVE IGS V REALNEM ČASU

PERFORMANCE ANALYSIS OF PPP POSITIONING METHOD BY USING IGS REAL-TIME SERVICE

Tatjana Kuzmić, Vladimir Bulatović

IZVLEČEK

Obstaja več metod za določanje položaja z uporabo globalnih navigacijskih satelitskih sistemov GNSS (angl. Global Navigation Satellite System*). Metode so klasificirane glede na dosegljivo točnost položaja, trajanje opazovanj za zanesljivo rešitev ter način določitve položaja – število sprejemnikov, vrsto uporabljenih opazovanj, izbrani GNSS-sistem ipd. Ena izmed pomembnejših za določitev položaja v GNSS je metoda PPP (angl.* Precise Point Positioning*), in sicer predvsem zaradi enostavnosti in stroškovne učinkovitosti. V članku predstavljamo metodo PPP, njene prednosti in omejitve ter napake, ki se lahko pojavijo pri določanju položaja z njo. Predstavljeni so rezultati analize empiričnega določanja položaja z metodo PPP, to so natančnost, čas konvergence, izpad podatkov, ponovljivost določitve položaja ter dosežena točnost na temelju treh serij opazovanj, vsake v trajanju po štiri ure. Pridobljene koordinate smo primerjali z referenčnimi koordinatami, ki smo jih določili s spletno storitvijo AUSPOS. Ugotovili smo, da je odstopanje med horizontalnimi koordinatami, določenimi s PPP-metodo, in referenčnimi vrednostmi, od 1 do 7 centimetrov, medtem ko so odstopanja pri višinah od 7 do 20 centimetrov.*

ABSTRACT

There are many positioning methods based on the usage of GNSS (Global Navigation Satellite System). They are classified according to the accuracy they can achieve, the time needed to obtain fixed solutions and the concept of positioning - number of used receivers, type of measurement, type of GNSS system, etc. One of the most important ways to do this is PPP (Precise Point Positioning) method, primarily because of its simplicity and cost-effectiveness. The paper describes PPP positioning method, its advantages and limitations, as well as the errors that can occur. It also provides an analysis of the performance of PPP method - precision, convergence time, loss of data reception, repeatability of positioning results and accuracy based on three measurement series in duration of 4 hours each, conducted on different days. By comparing the obtained coordinates with reference ones determined by AUSPOS web service, it can be concluded that the difference between these two sets of coordinates varies from 1 cm to 7 cm, while the accuracy of measured height is lower and the difference varies from 7 cm to 20 cm.

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1 INTRODUCTION

Precise Point Positioning (PPP) method is the process of determining geodetic coordinates of a point based on the observations of the GNSS receiver. in order to achieve the highest attainable accuracy (Sterle and Stopar. 2014). It has been demonstrated as a very powerful tool in geodetic and geodynamic applications. Its applications are common in areas such as crustal deformation monitoring. real-time meteorology. determination of low Earth orbiting satellites. precise positioning of mobile objects. etc. (Ge et al.. 2008). PPP method is also applied in the area of navigation. e.g. in aerial navigation (Krasuski. Wierzbicki and Jafernik. 2018). marine navigation (Marreiros. 2012). car navigation (Yu and Gao. 2017). land navigation (Martín et al.. 2012). etc. The impact of this surveying method on the positioning community is significant. Not only does it bring flexibility to field operations. but it also reduces labor and equipment costs and simplifies the operational logistics by eliminating the need for base station. However. PPP method requires an initialization period of at least a few tens of minutes for the carrier-phase ambiguities to converge to constant values and for the solution to reach its optimal precision (Seepersad and Bisnath. 2017). The usual minimum initialization period is 15-25 minutes.

Current carrier phase-based GNSS kinematic positioning systems are primarily based on double differencing data processing approach which is able to provide centimeter to decimeter-level positional accuracy in real time. The procedure of creating differences requires a simultaneous observation of GNSS satellite at the base station (reference location with precisely determined coordinates) and rover user stations. This makes the data acquisition process rather complicated and it reduces the possibility of using this method in numerous other applications. The need for the base station also increases labor and equipment costs and requires a greater effort of experts (Gao and Chen. 2004).

The availability of precise orbits of GPS satellites and clock parameters have enabled the development of PPP surveying method (Figure 1). This way of positioning is based on the processing of non-differential code and phase observations from a single receiver. Thus. it eliminates the constraints related to the differential processing of GNSS data. because the base station is not required. Therefore. PPP method offers an alternative to differential GNSS which is logistically simpler and of similar accuracy. Although PPP method does not require any base station. it should be emphasized that it requires accurate information about coordinates and clocks of GNSS satellites for its operation. They can be generated according to the network of permanent stations or downloaded from the IGS site (International GNSS Service) (Gao and Chen. 2004).

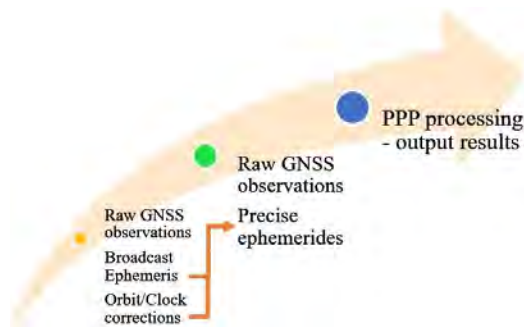Figure 1:   The concept of PPP positioning method.

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PPP positioning method has been tested and analyzed in many geodesic surveying such as presented below. In the study presented by (Alcay and Turgut. 2017). 3 IGS stations were used in order to evaluate the performance of PPP method. The results. obtained by using BKG Ntrip Client (BNC) software version 2.12. were examined in terms of both accuracy and precision. The results obtained after 20 minutes exhibited sub-decimeter level accuracy. In terms of standard deviation. which indicates the precision of the differences between coordinates determined by PPP method and true coordinates. the results showed relatively high values for all components (North. East. Up). The reason for high standard deviation values is directly related to the first 5 minutes of the obtained results. when the error was above centimeter level.

For the purpose of analyzing the usability and accuracy of web-based online processing services performed by (Alkan. Ozulu and Ilci. 2016). a data set of 24h which was statically collected from the station point was sent to various web-based online GNSS Data Processing Services. Both the services that implement PPP method and those based on relative method were tested. Additionally. in order to assess the attainable accuracy as a function of occupation time. a data set of 24-hour-data file was divided into several shorter sessions as 1. 2. 4. 6 and 12 hour sub-sessions. The obtained results indicated that it is possible to determine the positions with cm to dm level accuracy by using PPP technique. especially when using the data set having longer occupation time (2h or more). Web-based online services that utilize relative method provide more reliable and accurate results. The results showed that 2h occupation time is sufficient for cm level accuracy for horizontal component and dm (or less) level accuracy for height component. when considering PPP method (Alkan. Ozulu and Ilci. 2016).

The accuracy of PPP method and the convergence period of positioning results for agricultural and geodetic purposes were tested in (Abou-galala et al.. 2017). The experiment was realized on the basis of multi-day observations with 75 IGS stations. The accuracy of the static PPP method in northern. eastern. and vertical components were 4. 5 and 9 mm. respectively. They concluded that static PPP needs 60 min to reach five centimeter horizontal accuracy at the 95% confidence level and 24h to achieve one-centimeter horizontal accuracy at the 95% confidence level.

2 MATHEMATICAL MODEL OF PPP METHOD

Typically. PPP method implies the use of dual-frequency receiver whereby the code and phase measurements are linearly combined in order to eliminate first-order errors due to ionospheric correction (VTEC paremeter) and to evaluate the phase ambiguity by measurement model. Troposheric correction is also evaluated according to the measurement (Bisnath and Gao. 2007). By using dual-frequency receivers. it is possible to eliminate the influence of ionospheric delay of the first order through a linear combination of L1 and L2 observations. The higher-order ionospheric delay results from the interaction of the ionosphere and the magnetic field of the Earth. It depends on the slant total electron content (STEC). magnetic field parameters at the ionospheric pierce point (IPP) and the angle between the magnetic field and the direction of signal propagation (Liu et al.. 2016). The mathematical model of standard linear combination of dual-frequency receiver is given by (Gao and Chen. 2004; Liu et al.. 2016):

$$P_{IF} = \frac{f_1^2 P_1 - f_2^2 P_2}{f_1^2 - f_2^2} = \rho + c(dtr - dts) + \frac{q}{f_1 f_2 (f_1 + f_2)} + d_{rel} + d_{trop} + d_{mIF} + \varepsilon(P_{IF}) \tag{1}$$

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$$\phi_{IF} = \frac{f_1^2\phi_1 - f_2^2\phi_2}{f_1^2 - f_2^2} = \rho + c \cdot (dtr - dts) - \frac{q}{2f_1 f_2(f_1 + f_2)} + d_{rel} + d_{trop} + \frac{cf_1 N_1 - cf_2 N_2}{f_1^2 - f_2^2} + \delta_{wind-up} + \delta_{mIF} + \varepsilon(\phi_{IF}) \qquad (2)$$

where P_{IF} stands for the first-order ionosphere-free combination of pseudorange measurements. ϕ_{IF} is the first-order ionosphere-free combination of carrier phase measurements. P_i represents measured code observation (m). ϕ_i is measured phase observation (m). ρ stands for accurate geometric distance (m). c is speed of light (m/s). dtr represents receiver clock bias (s). dts is satellite clock bias (s). d_{rel} stands for relativistic correction (m). d_{trop} is tropospheric delay (m). f_i is frequency of signal (Hz). N_i is phase ambiguity. $\delta_{wind-up}$ represents phase wind-up term (m). d_{mIF} is the effect of multipath of measured code observation (m). δ_{mIF} is the effect of multipath of measured phase observation (m). $\varepsilon(P_{IF})$ represents measurement noise in code observations (m). $\varepsilon(\phi_{IF})$ represents measurement noise in phase observations (m) and q is second-order ionospheric effect.

The errors of the satellite orbit and clock in equations (1) and (2) are modeled using precise IGS data on orbits (e.g. format SP3/EPH) and clocks (e.g. format CLK). The remaining correction of the receiver clock bias and the troposphere delay in equations (1) and (2) can be estimated by PPP method. In the event of significant multipath effect. it is necessary to use a choke-ring antenna.

The estimation of tropospheric gradients is beneficial for both GPS positioning and tropospheric delay estimation (Gao and Chen. 2004). The gradient model improves the station position repeatability and precision in most cases. by using precise point positioning technique. It has been shown that estimating tropospheric gradients with high temporal resolution can achieve better positioning performance than the traditional strategy in which tropospheric gradients are estimated on a daily basis. In addition. with increasing elevation cutoff angles. the improvement in positioning repeatability decreases (Zhou et al. 2017). The following equation can be used to model the tropospheric impact (Gao and Chen. 2004):

$$d_{trop} = m_h(e)D_{hz} + m_w(e)D_{wz} + m_g(e)[G_N \cos(\alpha) + G_E \sin(\alpha)] \qquad (3)$$

where d_{trop} is tropospheric delay. D_{hz} and D_{wz} are zenith hydrostatic and wet delays. G_N and G_E stand for horizontal gradient in the north and east direction. $m_h(e)$ represents hydrostatic mapping function. $m_w(e)$ is wet mapping function. $m_g(e)$ stands for gradient mapping function and α and e are angles of azimuth and elevation at which the signal is received.

3 PERFORMANCE OF PPP METHOD AND ITS APPLICATIONS

In PPP method. there is a very small difference between the accuracy and the precision. Regarding the accuracy of the position in the north. east and up component at the 1σ level. PPP method can provide the accuracy of several centimeters in the static mode and decimeter accuracy in the kinematic mode. Both levels of accuracy can be achieved in post-processing or in real time (Bisnath and Gao. 2007).

The convergence period. i.e. the length of time required from a cold start to a centimeter-level positional solution. is about 20 minutes. The convergence period is determined by the measurement strength of the observables. geometry of problem. redundancy available for estimation problem. high correlation between estimated parameters and solution of ambiguity term. Initial solutions rely almost exclusively on pseudorange measurements. which incorporate the noise coming from signal (Bisnath and Gao. 2007). Satellite visibility problem is a critical issue that should be taken into consideration when implement-

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ing PPP method. since it has a significant effect on positioning accuracy. It is desirable to ensure that there are no limitations of the signals transmitted from satellite to receiver because it would lead to re-initialization process and accuracy degradation (tens of minutes of positioning with a resolution greater than decimeter). The addition of other GNSS systems offers more visible satellites to users. which in turn enhances the satellite geometry and improves the overall positioning solution. This in turn makes the PPP solution more feasible. especially in urban areas (Afifi and El-Rabbany. 2016).

As for the application of PPP method. it can be used in both real time and post-processing mode. One of the first applications of PPP method was for the post-processing of static geodetic data for rapid processing of GNSS tracking station data or crustal deformation monitoring. Another scientific application is the determination of precise LEO (Low Earth Orbit) satellite orbits close to the Earth. PPP method has primarily found its commercial use in precise agriculture. sensor positioning. navy applications. aerial mapping. etc. (Bisnath and Gao. 2007). Therefore. wherever precise positioning and navigation is required. whereby the locations are isolated or the areas are broad. and the infrastructure of the reference stations is not available. or it is very expensive for it to be temporarily installed. PPP method is recommended.

4 WEB-BASED ONLINE DATA PROCESSING SERVICES

Several institutions. research centres or organizations have developed web-based online GNSS processing services and they have started to become a viable alternative to the conventional data processing method. The only requirement for using these services. which are generally free of charge with limitless usage. is a computer having an internet connection and web browser. These services are designed to be as simple as possible for the user and with minimal input. Users of such systems have to upload or send collected RINEX data to the system by using the web site of these services. e-mail or ftp sites and select a few options such as static/kinematic mode. datum. antenna. etc. When the data is received to the service. processing starts and the results (processing report with the coordinates and other necessary information for analysing the results) are sent to the user in a short amount of time. Some of these services process not only the GPS but also the data of other systems. particularly those of GLONASS.

Table 1:   Post-processing web-based online services using relative and PPP technique solutions (Ocalan. 2016).

Solution	Service short name	Organization/Company	Data type	Post-processing mode	Software	Coordinates (Datum)
Relative	AUSPOS	Geoscience Australia	GPS	static	Bernese	ITRF2008
	OPUS	USA National Geodetic Survey	GPS	static/rapid static	PAGES	ITRF2008
	CSRS-PPP	Natural Resources Canada	GNSS	static/kinematic	NRCanPPP	ITRF2008
	GAPS	University of New Brunswick	GPS	static/kinematic	GAPS	ITRF2008
PPP	APPS	NASA Jet Propulsion Laboratory	GPS	static/kinematic	Gipsy	ITRF2008
	magic-GNSS	GMV Innovating Solutions	GNSS	static/kinematic	magic PPP	ITRF2008
	Trimble RTX	Trimble Navigation Limited	GNSS	Static	Trimble	ITRF2008

Web based services use relative (OPUS and AUSPOS) and precise point positioning solution approaches (CSRS-PPP. APPS. GAPS and magicGNSS). PPP-based services use the GNSS data collected only from a single receiver. precise satellite ephemerides and clock data by taking into account corrections like carrier phase wind-up. satellite antenna phase offset. solid and ocean tides. The services based on the relative

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solution use the fixed station points which relate to IGS and/or CORS Networks as reference points and calculate the coordinates of the points with the relative method. The use of these systems saves time and labour by eliminating the need for a reference station and time for gaining knowledge. training and usage of GNSS processing software (Alkan. Ozulu and Ilci 2016). Both PPP services and services based on relative method are listed in Table 1 with their basic characteristics.

OPUS uses RINEX data including dual-frequency observations for processing. OPUS processors make the solutions either static (2 hours < for data < 48 hours) or rapid static (15 minutes < for data < 2 hours) according to users observation file durations. Except for OPUS. which is limited to Central and North America. all of the online services provide GPS processing results for observations made anywhere in the world. AUSPOS is a free online GPS data processing service which determines the coordinates with a relative method by using nearby International GNSS Service and local Continuously Operating Reference Station (CORS) network points as reference stations (AUSPOS – Online GPS Processing Service. 2017). After submitting RINEX data to the service. system processor uses Bernese software for computations. The coordinates of points are provided in Geocentric Datum of Australia 1994 (GDA94) and ITRF2008 and these results are sent back to the user via email. Seven different RINEX data files with antenna types and heights may be submitted to the system simultaneously. However. some restrictions may appear depending on the length of GPS data. CSRS-PPP uses precise GPS orbit and clock products provided by IGS and Natural Resources Canada (NRCan). and estimates single station positions in static and kinematic modes. CSRS estimations are computed from carrier phase or code pseudorange observations of both single and dual-frequency receivers. Both GAPS and APPS services can process GPS data in both static and kinematic modes. GAPS does not require any membership for use. while APPS service requires membership. However. while GAPS uses IGS rapid and final clock and orbit products in processing. APPS uses final. rapid. ultra rapid and precise GPS orbit and clock products of JPL. The users may also use Site Displacement Effects (Solid Earth Tides and Ocean Tidal Loading) in processing if they prefer. MagicGNSS is a free software developed by Spanish GMV firm that processes dual-frequency observation files. which are collected in static and kinematic modes. by using rapid and final GPS orbits and clock products of IGS. There is also a selection opportunity for users to process GPS-only. GLONASS-only. GPS+GLONASS RINEX data (Ocalan. Erdogan and Tunaliogl. 2013). Trimble RTX works anywhere in the world and is based on a proprietary Trimble 100+ worldwide CORS network. Accuracy is 2 cm with 1-hour of observation data; 1 cm with 24-hours. Files longer than 24-hours are not accepted. RTX uses GPS. GLONASS and QZSS satellites. RTX supports a limited number of receivers (Trimble) and a relatively small subset of IGS modeled antennas.

5 EXPERIMENTAL SETUP AND RESULTS

5.1 Experimental setup

In this study. the positioning performance of PPP method was examined. Data from Paracin station. which belongs to the Gentoo permanent network. were collected in three series on different days. in duration of 4 hours each. The station is equipped with dual-frequency receiver. which records GPS and GLONASS satellites. The data set containing PPP coordinates for Paracin station were obtained using BKG Ntrip Client (BNC) software (BKG GNSS Data Center. 2017). Coordinate results were derived at intervals

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of 1 second. In order to compare the results of PPP positioning method. RINEX data obtained from Paracin station were submitted to AUSPOS service. In this computation. an IGS Rapid Orbit product was used. as well as GPS-only data since this service can not process data from other constellations. such as Glonass. The coordinates provided by this service were adopted as reference.

After the access parameters for permanent station Paracin had been created. data streams were downloaded using NTRIP Broadcaster. i.e. IP address. host. username. password. and type of mounting within BNC software were defined.

An account was created on IGS website in order to access broadcast ephemerides and corrections. The broadcast ephemeris for GPS and GLONASS satellites were downloaded from the caster mgex.igs-ip.net in real time in format RTCM_3. These data were produced using BKG's BNC software. The data stream was derived from a major part of receivers in real-time IGS global network. A complete set of messages was repeated every 5 seconds.

Clock corrections and the positions of the satellites were downloaded from the caster products.igs-ip.net as a combination of GPS and GLONASS corrections through Kalman filter which requires a convergence time of several minutes in order to reach full accuracy. In this approach. satellite clocks estimated by different analysis centers are used as pseudo observations within the adjustment process. Each observation is modeled as a linear function of three estimated parameters: offset specific for analysis centers. offset of specific satellite common to all analysis centers and actual correction of satellite's clock which represents the result of combination. These three parameter types differ by their statistical properties. Satellite clock offsets are assumed to be static parameters. while the offsets of the analysis center and satellites are stochastic parameters with white noise. Recursive algorithm is used to detect the orbit outliers by computing the greatest difference between the mean satellite position and the specific position determined by the analysis center. If this value is greater than the threshold. the corrections of the affiliated analysis center are ignored for this affected epoch (The International GNSS Service. 2017).

Collected data from the permanent station. ephemerides and clock data. and satellite positions were processed in BNC software. Graphic displays were created in RTK Plot program as a library of RTKLIB software package (RTKLIB: An Open Source Program Package for GNSS Positioning. 2017).

5.2 Experimental results

AUSPOS Online GPS Processing Service was used in order to determine reference coordinates of the station in Paracin. These coordinates are provided in ITRF08 framework and are given in Table 2. together with their positional uncertainty at the 95% confidence level. These coordinates were determined with uncertainty of several milimeters. while the uncertainty of obtained height is around 2 cm. which justifies their use as reference ones.

Table 2:   Reference coordinates of Paracin station determined by AUSPOS processing service; positioning errors of coordinates

Position of receiver at reference station in Paracin		
φ	λ	h
43.752265092 °	21.435698794 °	188.448 m
Positioning errors (95% conf. level)		
0.005 m	0.006 m	0.018 m

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By analyzing the .log file at BNC exit in all three series of measurements. it was noticed that the error was several meters at the start of measurement. During the first 20 minutes of positioning. the error gradually decreased and amounted to a few centimeters. This was due to an unknown fractional part of the satellite ambiguity. and. hence. the carrier phase ambiguities were firstly estimated as floating. This entailed initialisation time required for ambiguity-fixed solution to be successful and for position to reach centimeter level accuracy. Because of this. the data collected during the first 20 minutes in each of three measurement series were eliminated from further analysis.

Table 3 summarizes determined coordinates of the receiver at the station in Paracin for all three series of measurements. obtained by using PPP method and BNC software. as well as minimum. maximum and median value of determined coordinates. Table 4 gives average. minimum. maximum and median error value for all three position components (φ. λ. h) separately and for each measurement series.

Table 3:   Average. minimum. maximum and median value of position components (φ. λ. h) determined by PPP method in BNC software; series 1. 2 and 3
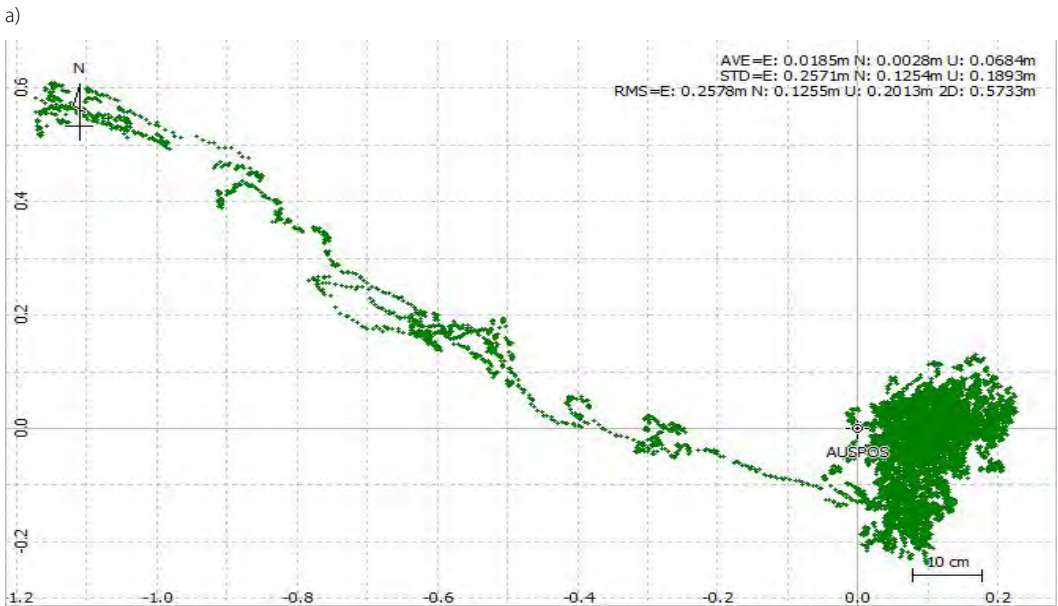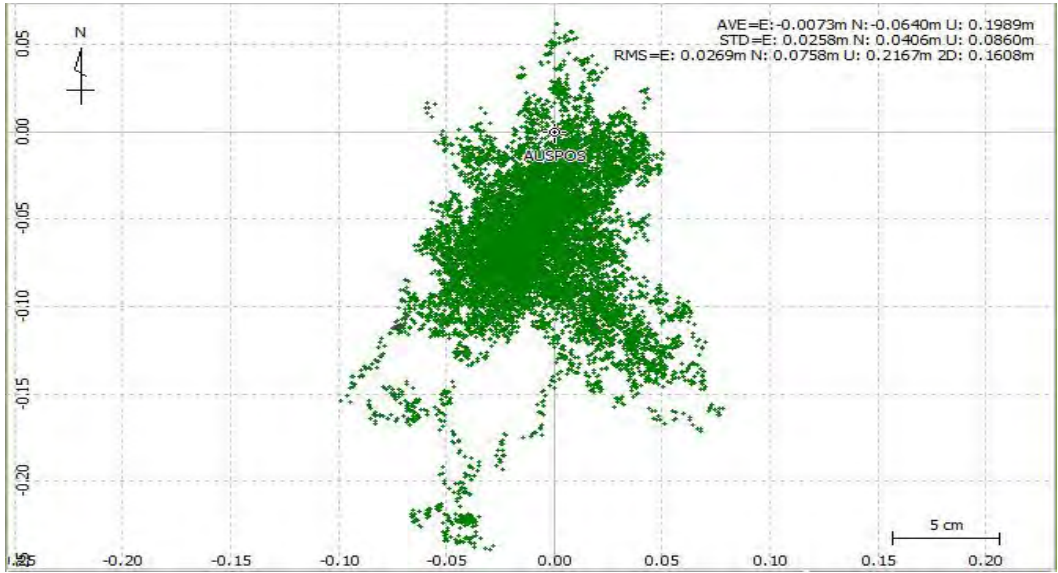
Series		Coordinate			
		Average value	Minimum value	Maximum value	Median value
1.	φ	43.75226452 º	43.75226294 º	43.75226565 º	43.75226454 º
	λ	21.43569870 º	21.43569757 º	21.43569976 º	21.43569870 º
	h	188.647 m	188.434 m	189.020 m	188.645 m
2.	φ	43.75226512 º	43.75226294 º	43.75227058 º	43.75226507 º
	λ	21.43569902 º	21.43568422 º	21.43570160 º	21.43569987 º
	h	188.516 m	187.673 m	188.962 m	188.511 m
3.	φ	43.75226447 º	43.75226209 º	43.75226638 º	43.75226490 º
	λ	21.43569871 º	21.43569235 º	21.43569997 º	21.43569898 º
	h	188.573 m	187.797 m	188.999 m	188.568 m

Table 4:   Average. minimum. maximum and median error value of position components (φ. λ. h) determined by PPP method in BNC software; series 1. 2 and 3
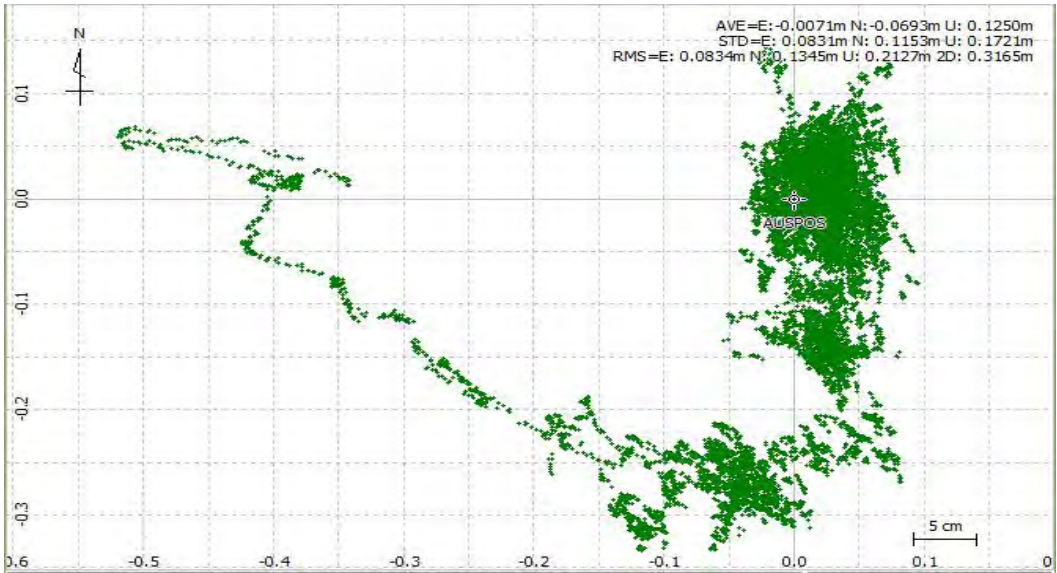
Series		Error value			
		Average error value (m)	Minimum error value (m)	Maximum error value (m)	Median error value (m)
1.	φ	0.030	0.022	0.075	0.025
	λ	0.017	0.015	0.028	0.017
	h	0.026	0.020	0.042	0.026
2.	φ	0.038	0.026	0.074	0.032
	λ	0.028	0.017	0.125	0.021
	h	0.031	0.021	0.050	0.029
3.	φ	0.033	0.025	0.082	0.029
	λ	0.023	0.018	0.063	0.020
	h	0.032	0.021	0.061	0.031

Graph 1. presents the positions of Paracin station determined by PPP method at 1 second interval in BNC software (green dots) relative to the reference position determined by AUSPOS web service. for

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all three measurement series separately. On the graph. horizontal and vertical axes represent the differences between reference north and east position component derived based on the reference coordinates determined by AUSPOS service and north and east position component obtained based on the coordinates provided by PPP method in BNC software at 1 second interval. respectively. On the graph. value AVE reperesents the average difference between the reference coordinates and coordinates obtained by PPP method. for north. east and up component separately. Value STD and RMS (Root Mean Square) represent average standard deviation and RMS error.

a)

b)

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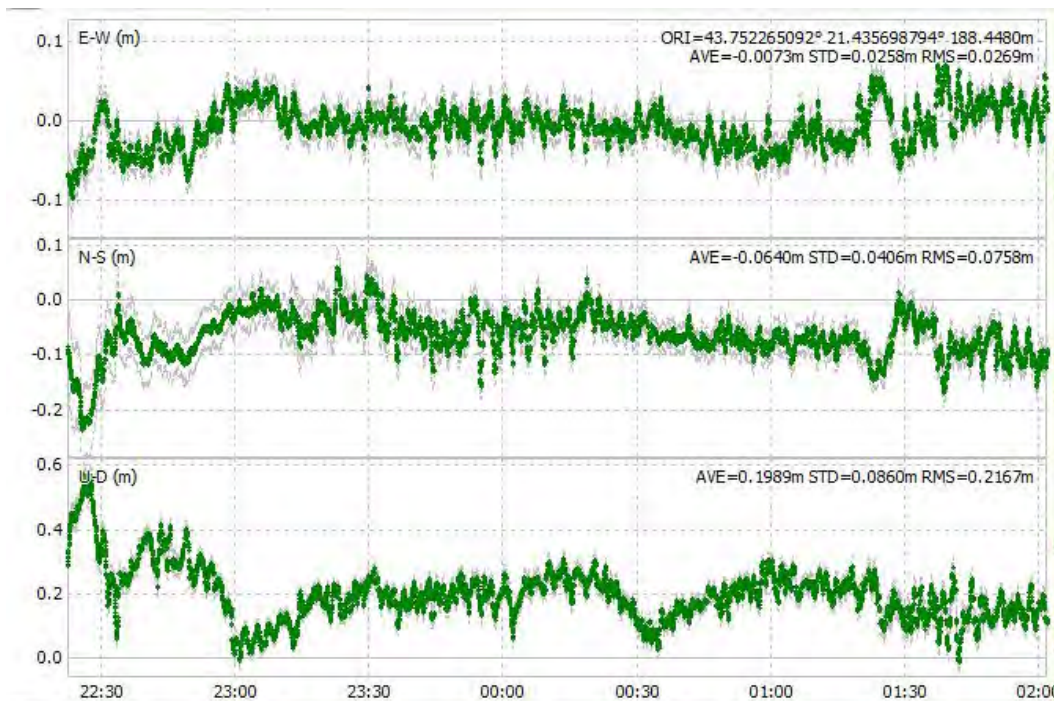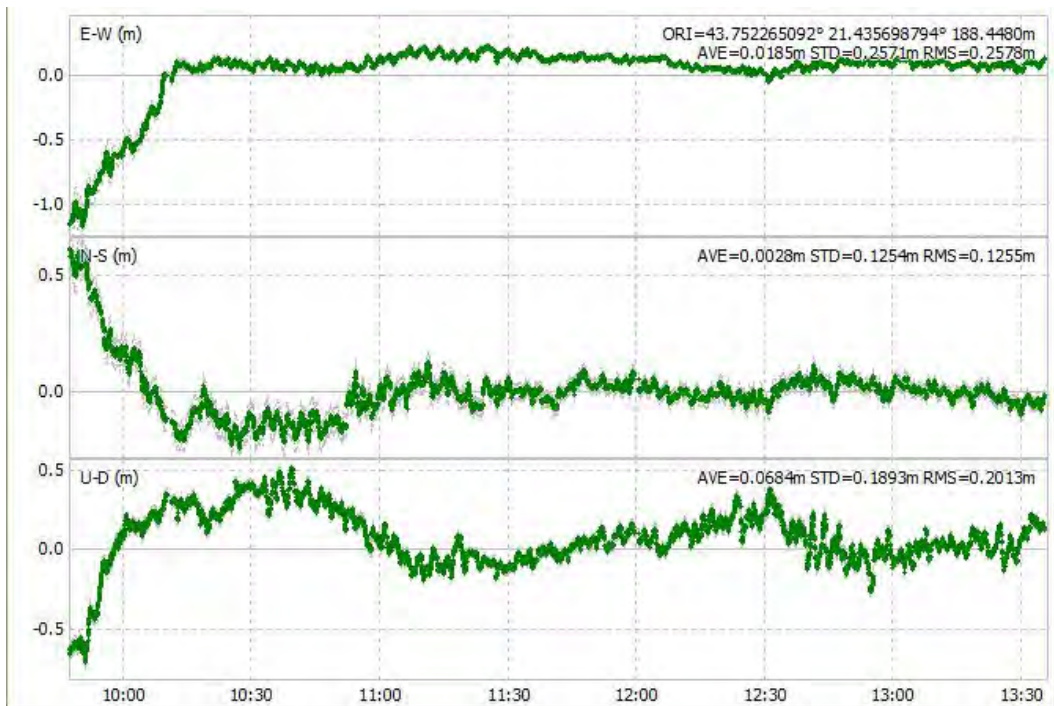
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c)

Graph 1. Determined positions of Paracin station by PPP method in BNC software relative to reference position determined by AUSPOS service; series 1 (a). 2 (b) and 3 (c).

From these graphs. it can be seen that the positions of the receiver determined by PPP method are near the reference value. while the values of average errors that occur in all three series of measurements are within several centimeters. Most of the positions determined by PPP method are equally concentrated around the reference value. especially in the first measurement series. The graphs clearly show that a part of obtained positions is further apart from the reference position in the case of the second and third series. Based on the data given in Table 4. it can be seen that in all three measurement series. the positions determined by PPP method have similar average error value. when compared according to specific position element. As for latitude. the average error value is around 3 cm. whereas this value is around 2 cm when it comes to longitude. Height is determined with an average error around 3 cm. Minimum. maximum and median value for three measurement series. when compared within specific position element. are similar and differ for ±1 cm. Maximum occurred value of longitude error (12 cm) is obtained in the second series and it differs from longitude errors in the first and third series for 10 cm and 6 cm. respectively. This error value is related to the beginning of observation.
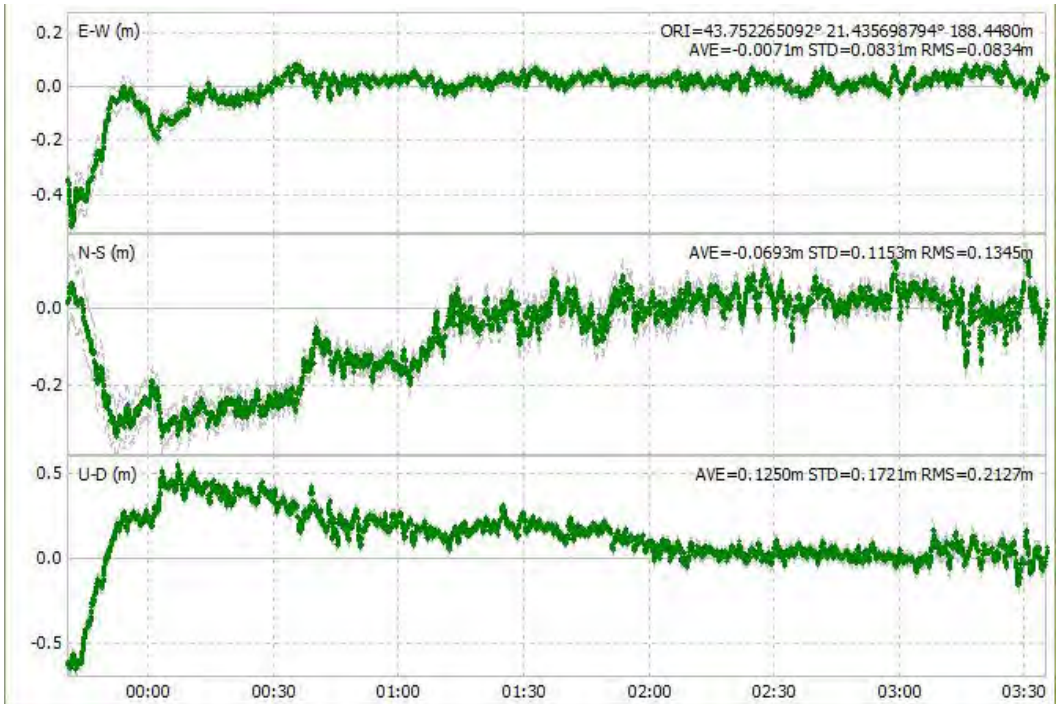
In Graph 2. the deviations of the position elements determined by PPP method are shown in relation to the reference value. determined by AUSPOS service for all three measurement series. The green points in the plot below represent the solution value plus and minus standard deviation. represented by gray lines. On the graph. the horizontal axis represents the time of recorded solution and the vertical axis represents deviation of position. separately shown for all three position components (East-West. North-South. Up-Down). Moreover. value AVE reperesents the average difference between the reference coordinates and the coordinates obtained by PPP method. for North. East and Up component separately. Values STD and RMS (Root Mean Square) represent average standard deviation and RMS error.

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a)

b)

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c)

Graph 2.   Deviation of position elements; series 1 (a). 2 (b) and 3 (c).

Table 5 shows receiver clock errors and Table 6 shows apriori. correction and error value of tropospheric delay for all three measurement series.

Table 5:   Receiver clock errors; series 1. 2 and 3.

	Value of receiver clock bias (m)	Error of receiver clock bias (m)	Value of receiver clock bias (µs)	Error of receiver clock bias (µs)
Series 1	2.383	0.050	0.0079	0.00017
Series 2	0.275	0.056	0.0009	0.00019
Series 3	1.997	0.054	0.0067	0.00018

Table 6:   Apriori value. correction and error of tropospheric delay; series 1. 2 and 3

	Apriori value of tropospheric delay (m)	Correction value of tropospheric delay (m)	Error of tropospheric delay (m)
Series 1	2.342	0.072	0.001
Series 2	2.342	0.165	0.003
Series 3	2.342	0.095	0.002

Based on the data presented in Table 5. it can be observed that the value of receiver clock bias was estimated with almost the same level of accuracy in all three series. The value of clock bias was greatest in the first series. while the smallest value of clock bias was calculated in the second series. When considering modelling tropospheric delay (Table 6). the biggest error and correction for apriori value of tropospheric

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delay was calculated in the second series. The accuracy of estimating tropospheric delay does not differ much between three series. but the greatest accuracy was achieved in the first series. This is related to the accuracy of obtained positions. which was greatest in the first measurement series. as shown in Table 4.

5.3 Discussion of obtained results

Table 7 shows the mean deviation value of determined coordinates in relation to the reference value. as well as standard deviation and RMS error for all three series. It can be concluded that the coordinates determined by PPP method differ from reference ones from 1 cm to 7 cm. while the height differs from 7 cm to 20 cm. Based on the average values of standard deviation in the first measurement series. it is confirmed that it does not come to great scattering of results. while the average values of standard deviation in the second and third measurement series are higher. The latter corresponds to scattering of part of positions as can be seen on Graph 1 b and c. The differences of average standard deviation values. when comparing the second and third series with the first one. vary from 7 cm to 23 cm. The difference of 23 cm occurs in the second measurement series in east component. which is in relation with the greatest error and deviation observed also in this case. RMS (Root Mean Square) values also confirm this conclusion.

Table 7: Positioning statistics. series 1. 2 and 3

	Series 1			Series 2			Series 3		
	North	East	Height	North	East	Height	North	East	Height
Mean deviation (m)	0.064	0.007	0.199	0.003	0.019	0.068	0.069	0.007	0.125
St. deviation (m)	0.041	0.026	0.086	0.125	0.257	0.189	0.115	0.083	0.172
RMS (m)	0.076	0.027	0.217	0.126	0.258	0.201	0.135	0.083	0.213

By analyzing the data obtained at BNC exit. it can be noted that there are no major interruptions in obtaining a fixed solution. The total number of noticeable GPS satellites in all series of measurements ranges from 9 to 10. Although the settings in the software were set to the usage of GPS and Glonass satellites. observations to Glonass constellation did not enter the calculation of position. The used version of BNC software was not up-to-date (2.11.2). but this software is constantly being upgraded. so the inclusion of other GNSS systems can be part of further research in newer versions of BNC. This version also reported bugs regarding Saastamoinen tropospheric correction for very high elevation receivers and GLONASS code biases (BKG GNSS Data Center. 2017). The data displayed in the paper were gathered in three series on different days. with the observation period of 4h. Because of low accuracy obtained at the beginning of data collecting. first 20 minutes of observation were eliminated from further analysis in all series. Based on the graphics of determined positions of the points in three series of measurements and presented data. it can be concluded that the period of 20 minutes at the beginning of data collecting was enough to determine the position of Paracin station with centimeter accuracy.

When comparing the obtained results with similar experiments presented in Introduction. it is confirmed that 20 minute convergence time is sufficient to achieve sub-decimeter level of accuracy. A similar level of accuracy has been obtained in the research provided by (Alkan. Ozulu and Ilci. 2016). (Alcay and Turgut. 2017) have achieved a lower level of accuracy. but that was due to shorter observation time and because they did not exclude low accuracy observations from the beginning of measurement from the analysis. (Abou-galala et al.. 2017) have obtained better accuracy results. but the observation time in

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this experiment was much longer – around 24h.

6 CONCLUSION

Due to the increased number of providers of clock and orbit corrections for real-time data processing and post-processing. PPP method has become widely applied. Recognizing some of the advantages. such as work time and cost effectiveness. many users have implemented this method instead of traditional relative positioning. The great advantage of this method is that it does not require the use of more than one receiver. which makes it considerably more economical and easier to operate. The PPP method currently has certain shortcomings. and one of the biggest is the time needed for reaching a fixed solution.

In this paper. the accuracy and performance of PPP method were analyzed based on three measurement series that lasted 4 hours each and were conducted on three different days. The obtained coordinates were compared to the reference coordinates determined by AUSPOS service. Based on the experiments. it can be concluded that it takes approximately 20 minutes for accuracy of the coordinates to fall from decimeter to centimeter level. However. by introducing other GNSS systems. there is a possibility that convergence time will be further reduced. which could be part of further research. The results of the experiment showed that PPP method can achieve the accuracy of point coordinates of several centimeters after 4 hours of collecting data. When considering the accuracy of obtained height in all three measurement series. its value was slightly lower than that of the obtained point coordinates. Average coordinate deviation in relation to reference coordinates ranged from 1 cm to 7 cm. while the height differed from 7 cm to 20 cm. Values of RMS error and standard deviation were slightly higher in the second and third measurement series. which is related to larger scattering of part of the obtained results in these two series. This can be also observed on Graph 1. Based on the three repetitions of the experiment during different days. it can be concluded that PPP method gives a fairly balanced result in terms of position with centimeter level accuracy. while in case of height. the obtained results differ from reference height at decimeter level.

Literature and references:

Abou-galala. M.. Rabah. M.. Kaloop. M.. Zidan. Z. M. (2017). Assessment of the accuracy and convergence period of Precise Point Positioning. Alexandria Engineering Journal. DOI: https://dx.doi.org/10.1016/j.aej.2017.04.019

Afifi. A.. El-Rabbany. A. (2016). Precise Point Positioning Using Triple GNSS Constellations in Various Modes. Sensors (Switzerland). 16 (6). DOI: https://doi.org/10.3390/s16060779

Alcay. S.. Turgut. M. (2017). Performance Evaluation of Real-Time Precise Point Positioning Method. World Multidisciplinary Earth Sciences Symposium. 95 (1–5). DOI: https://doi.org/10.1088/1755-1315/95/3/032023

Alkan. R. M.. Ozulu. I. M.. Ilci. V. (2016). Web - based GNSS Data Processing Services as an Alternative to Conventional Processing Technique. FIG Working Week 2016 Recovery from Disaster Christchurch. New Zealand.

AUSPOS – Online GPS Processing Service. http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos. accessed 23. 7. 2017.

Bisnath. S.. Gao. Y. (2007). Current state of precise point positioning and future prospects and limitations. Proceedings of IUGG 24th General Assembly. 615–623. DOI: https://doi.org/10.1007/978-3-540-85426-5_71

BKG GNSS Data Center. https://igs.bkg.bund.de/index/index. accessed 5. 6. 2017.

Gao. Y.. Chen. K. (2004). Performance Analysis of Precise Point Positioning Using Real-Time Orbit and Clock Products. Journal of Global Positioning Systems. 3 (1&2). 95–100. DOI: https://doi.org/10.5081/jgps.3.1.95

Ge. M.. Gendt. G.. Rothacher. M.. Shi. C.. Liu. J. (2008). Resolution of GPS carrier-phase ambiguities in Precise Point Positioning (PPP) with daily observations. Journal of Geodesy. 82 (7). 389–399. DOI: https://doi.org/10.1007/s00190-007-0187-4

Krasuski. K.. Wierzbicki. D.. Jafernik. H. (2018). Utilization PPP method in aircraft positioning in post-processing mode. Aircraft Engineering and Aerospace Technology. 90 (1). 202–209. DOI: https://doi.org/10.1108/AEAT-05-2016-0078

Liu. Z.. Yangyang. L.. Jinyun. G.. Fei. L. (2016). Influence of Higher-Order Ionospheric Delay Correction on GPS Precise Orbit Determination and Precise Positioning.

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Geodesy and Geodynamics. 7 (5). 369–376. DOI: http://dx.doi.org/10.1016/j.geog.2016.06.005

Marreiros. J. P. R. (2012). Kinematic GNSS Precise Point Positioning Application to marine platforms. PhD thesis. Porto: University of Porto. Faculty of Sciences.

https://repositorio-aberto.up.pt/bitstream/10216/66684/2/24150.pdf. accessed 20. 9. 2018.

Martín. A.. Anquela. A.. Berné. J.. Sanmartin. M. (2012). Kinematic GNSS-PPP results from various software packages and raw data configurations. Scientific Research and Essays. 7 (3). 419–431. DOI: https://doi.org/10.5897/SRE11.1885

Ocalan. T. (2016). Accuracy assessment of GPS precise point Positioning (PPP) technique using different web-based online services in a forest environment. Sumarski List. 140 (7–8). 357–368.

Ocalan. T.. Erdogan. B.. Tunaliogl. N. (2013). Analysis of Web-Based Online Services for GPS Relative and Precise Point Positioning Techniques. Faculty of Civil Engineering Department of Geomatic Engineering Davutpasa Campus TR-34220 Esenler-İstanbul-Turkey. 191–207. DOI: https://doi.org/10.1590/S1982-21702013000200003

RTKLIB: An Open Source Program Package for GNSS Positioning. http://www.rtklib.com/. accessed 1. 6. 2017.

Seepersad. G.. Bisnath. S. (2017). An assessment of the interoperability of PPP-AR network products. The Journal of Global Positioning Systems. 15 (4). DOI: https://doi.org/10.1186/s41445-017-0009-9

Sterle. O.. Stopar. B. (2014). PPP method for static GNSS survey. Geodetski Vestnik. 58 (3). 466–481. DOI: https://doi.org/10.15292/geodetski-vestnik.2014.03.466-481

The International GNSS Service (IGS). http://www.igs.org/rts/products. accessed 18. 7. 2017.

Yu. X.. Gao. J. (2017). Kinematic Precise Point Positioning Using Multi-Constellation Global Navigation Satellite System (GNSS) Observations. ISPRS International Journal of Geo-Information. 6 (6). DOI: https://doi.org/10.3390/ijgi6010006

Zhou. F.. Li. X.. Li. W.. Chen. W.. Dong. D.. Wickert. J.. Schuh. H. (2017). The Impact of Estimating High-Resolution Tropospheric Gradients on Multi-Gnss Precise Positioning. Sensors (Switzerland). 17 (4). DOI: https://doi.org/10.3390/s17040756

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