Kinematic PPP Positioning Using Different Processing Platforms

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Key words: GNSS, PPP, Online Processing, Kinematic Surveying, Obruk Dam

SUMMARY

In recent years, several organizations, mainly the International GNSS Service (IGS), have been providing accurate satellite orbit and clock products with various accuracy levels to the researchers. With the advent of these products, a new technique called Precise Point Positioning (PPP) has started to make accurate positioning utilizing undifferenced carrier-phase and pseudorange observations collected by only a single GNSS receiver. The technique has attracted wide interest by the academic and commercial communities in the last decade due to its having advantages like easy use, simple field operations, no base station requirement, and provides cost effective high accuracy positioning. This technique provides reliable and accurate global solutions to its users in a dm to cm level of positional accuracy in static and kinematic modes.

In this study, the kinematic accuracy performance of the different PPP processing platform was assessed. For this purpose, a kinematic test was conducted in a dynamic environment, Obruk Dam Lake, Çorum City, Turkey. The collected data were processed using the different processing platforms and compared to reference trajectory obtained from high accurate post-processing relative technique. The results obtained were investigated in terms of usability and accuracy provided.

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1. INTRODUCTION

In recent years, several organizations, mainly the International GNSS Service (IGS), have been providing accurate satellite orbit and clock products with different accuracy levels, i.e. Ultra-Rapid, Rapid, Final and Real-Time, to the researchers. These products are produced for the GPS and GLONASS constellations and served free of charge through the web page. With emerge of these products, new techniques using only single GNSS receiver data have been studied as an alternative to the differential technique. One of is Precise Point Positioning (PPP) that has attracted wide interest by academic and commercial community in the last decade. This absolute positioning technique uses undifferenced carrier phase and pseudorange observations besides precise orbit and clock data for accurate positioning (Mireault et al., 2008; Guo, 2015; Farah, 2015; Gross et al., 2016). PPP technique does not require any reference station data like Single-baseline or Network Real-Time Kinematic (RTK) techniques. Moreover, PPP minimizes the cost of personal, equipment and pre-planning of the field survey. Using only single dual-frequency Global Navigation Satellite System (GNSS) receiver, PPP provides reliable and accurate global solution to the users in cm and decimeter level positioning accuracy for static and kinematic positioning techniques, respectively (Zumberge et al., 1997; Kouba and Héroux, 2001; Kouba, 2003; Choy et al., 2007; Tsakiri, 2008; El-Mowafy, 2011; Anquela et al., 2013; Lou et al., 2016; Choy et al., 2017; Kouba et al., 2017). The PPP technique has become a strong alternative to the differential GNSS methods due to its easy use, simple field operations, no base station requirement, and provides cost effective high accuracy positioning.

In this study, a field experiment was conducted to test the kinematic positioning performance of different PPP processing platforms. For this purpose, the collected kinematic data were processed using scientific/commercial software, i.e. RTKLIB, gLAB and GrafNav and with online web-based PPP processing services, i.e. CSRS-PPP, magicGNSS. These results were compared with the reference trajectory obtained from post-processing relative kinematic technique solutions. Information about the experiment and the related results are given in the following sections.

2. MATHEMATICAL MODEL FOR MULTI-GNSS PPP

At the beginning, International GNSS Service (IGS) and a number of organizations served precise orbit and clock products for only GPS system. As a result of the developments in satellite-based positioning technique that have taken place in the following time, the availability of precise orbit and clock products for GPS, GLONASS, Galileo and BeiDou provided the multi-GNSS PPP with the combination of different constellations. This improves the positioning accuracy and reduces the convergence time for PPP method (Cai et al., 2015).

This also provides the usability of the PPP to be used in areas with GNSS signal either being blocked or strongly degraded by obstacles like urban canyons, heavy tree cover, open-pit mines and extreme marine environments etc.

Based on a multi-frequency multi-GNSS receiver data, the following formulas express the pseudorange and carrier-phase observations on *i*th (i = 1, 2) frequency (Cai et al., 2015):

$$P_i^j = \rho^j + cdt - cdT^j + d_{orb}^j + d_{trop}^j + d_{ion/Li}^j + b_{Pi}^j + \varepsilon_{Pi}^j \quad (1)$$

$$\Phi_i^j = \rho^j + cdt - cdT^j + d_{orb}^j + d_{trop}^j - d_{ion/Li}^j + B_i^j + \varepsilon_{\Phi i}^j \quad (2)$$

where

j : GNSS satellite,
P_i : the measured pseudorange on *i*th frequency (m),
Φ_i : the measured carrier phase on *i*th frequency (m),
ρ : the true geometric range (m),
c : the speed of light (m/s),
dt : the receiver clock offset (s),
dT : the satellite clock offset (s),
d_{orb} : the satellite orbit error (m),
d_{trop} : the tropospheric delay (m),
$d_{ion/Li}$: the ionospheric delay on *i*th frequency (m),
b_{Pi} : the hardware delay bias in the code observations on *i*th frequency (m),
B_i : the phase ambiguity term on ith frequency (m), (includes the receiver and satellite initial phase biases and phase hardware delay biases),
ε_{Pi} *and* $\varepsilon_{\Phi i}$: the code and phase observation noises respectively, including multipath (m).

In order to remove the first-order ionospheric delay errors, ionosphere-free combined observables are normally utilized for PPP. In this case, ionosphere-free combined code and carrier phase observables for a satellite *j* can be written as follows:

$$P_{IF}^j = (f_1^2 . P_1^j - f_2^2 . P_2^j)/(f_1^2 - f_2^2) \quad (3)$$

$$\Phi_{IF}^j = (f_1^2 . \Phi_1^j - f_2^2 . \Phi_2^j)/(f_1^2 - f_2^2) \quad (4)$$

where,

P_{IF} : the ionosphere-free code observable (m),
Φ_{IF} : the ionosphere-free carrier-phase observable (m),
f_1 and f_2 : two carrier-phase frequencies in Hertz (the

frequencies are different between GLONASS satellites).

It should be noted that, in order to estimate the more accurate PPP-derived coordinates, many corrections like carrier-phase wind-up, satellite antenna offsets and variations, solid earth tide, and ocean tide loading corrections should be modelled in addition to using of the precise products.

3. PPP PROCESSING PLATFORMS

There are various alternatives to be used in order to obtain PPP-derived coordinates and they can be categorized into different processing platforms like;

- Scientific (Academic) Software (e.g. BERNESE, GAMIT, GIPSY OASIS, RTKLIB, and gLAB),
- Commercial Software (e.g. GrafNav),
- Web-based Online Processing Services (e.g. CSRS, APPS, GAPS, and magicGNSS)
- In-house software.

Each of the processing platforms mentioned has its own advantages and disadvantages. For example, the first kind of software have been developed for research and educational purpose and they require advanced GNSS knowledge and generally high license fee. There is also a need for skilled and experienced personnel to use these software as well as commercial ones. Recently, web-based online GNSS processing services have been developed by several institutions, research centres or organizations as an alternative to conventional GNSS data processing methods and served to users all over the world. The users of these services do not need a processing software and their complex processing strategies. In-house softwares are generally not very practical since they are coded for researchers to obtain results based on their knowledge and requirements. Also, it is hard to update these softwares regularly (Alkan et al., 2017). These alternatives are preferred depending on users' expectations, opportunities, and knowledge level of GNSS.

Within this study, two different PPP processing platforms, i.e. scientific/commercial software and online processing services were used to estimate PPP-derived coordinates. The general information about the used PPP processing platforms are given in the following chapter.

3.1. Scientific/Commercial PPP Post-Processing Software

There are scientific (or academic) and commercial software running on personal computers developed for PPP-based coordinate calculation. These software, especially scientific ones require, a deep GNSS knowledge and experience (also advanced computer skills) and the users can process the collected data by making selection upon their information and experience level. While this is providing a significant flexibility for professional users, it can become a major problem for users who do not have sufficient knowledge and experience.

Users of commercial software should similarly require a GNSS background in a certain level. However, such software is relatively user-friendly when compared to scientific one. Such windows based (or optional) software offer to users generally accepted/used options in the literature, some of which are offered as default options. These softwares usually require a license fee, which can be quite high for some cases.

In this study, different post-processing software, namely, RTKLIB, gLAB and GrafNav, were used to calculate PPP-derived coordinates. A brief overview of the software used in this study is given as follows.

***i-)* RTKLIB:** RTKLIB is an open source program package for multi-GNSS positioning software developed by Tomoji Takasu from the Tokyo University of Marine Science and Technology in Japan. RTKLIB can process collected data with standard and precise positioning techniques by using different satellite constellations, GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS. It supports many positioning modes including DGPS/DGNSS, Kinematic, Static, Moving-Baseline, PPP-Kinematic, PPP-Static and PPP-Fixed modes. This non-commercial software can achieve forward, backward and combined processing solutions for GNSS data. The program allows many processing options and detailed analysis for the evaluation of the results to the users. More detailed information about the RTKLIB software is available at http://www.rtklib.com.

***ii-)* gLAB:** gLAB GNSS analysis tool was developed by research group of Astronomy and Geomatics (gAGE) from the Universitat Politechnica de Catalunya (UPC) for European Space Agency (ESA). The GNSS-Lab Tool suite (gLAB) is an advanced interactive educational multipurpose package to process and analyse GNSS data. The gLAB software tool performs a precise modelling of the GNSS observables (code and phase) at the centimetre level, allowing Standard Point Positioning (SPP), Precise Point Positioning (PPP), differential correction from SBAS and Differential (DGNSS) modes. Although, it is planning to process all the GNSS systems (GPS, GLONASS and Galileo etc.) in future, now, gLAB is only ability to perform GPS data. gLAB is a flexible software, able to run under Linux and Windows operating systems. It was served to Universities and GNSS professionals free of charge by the European Space Agency (ESA). The software and more detailed information about the software are available at http://gage.upc.edu/gLAB.

***iii-)* GrafNav:** GrafNav is a commercial GNSS post-processing software developed by Waypoint Products Group of Novatel. This software allows users to compute high accuracy static and kinematic GNSS solution from their raw observation data collected with single or multi-frequency receivers. While GPS, GLONASS and Beidou data can be processed in PPP mode, GPS, GLONASS, BeiDou, Galileo and QZSS data can be processed in differential mode. Using precise satellite clock and orbit data, kinematic trajectories can be processed with sub-5 cm positioning accuracy in PPP mode. Moreover, this software has the ability to combine forward and backward processing results for higher accuracy, and give wide options in datum and map projections. Users are able to obtain many statistical results about the processing results and plot the many different results like DOP, skyplot, number of satellites and etc. More detailed information about this software is available at https://www.novatel.com/products/software/grafnav.

3.2. Web-Based Online GNSS Processing Services

A number of institutions, universities, research centres and organizations worldwide have developed online GNSS processing services for estimating the coordinates using differential (relative) and/or PPP techniques. These services are very easy to use and often offer unlimited access to their users free. The requirements of the users of these services are a web browser and a computer connected to the Internet and a valid e-mail account. For these services, uploading GNSS data collected on the field via webpage or e-mail/FTP with selection of static/kinematic mode, input of antenna type/height, and selection of datum are generally enough. This service generally requires basic level of GNSS information. After submission, the services start to evaluate the data in a considerably very short time, within few minutes, results and some reports are sent to the introduced user's e-mail address. Some of these services provide users with flexibility and in some cases higher positioning accuracy, not only by using GPS data, but also by using data from other satellite systems, especially GLONASS. One of the most important factors in the widespread use of these services, which are accepted by surveying authorities, is the accuracy they provide. One of the most important reasons for this success is the use of scientific/academic GNSS processing software such as BERNESE, GAMIT, PAGES by applying generally accepted processing parameters in the literature. The major disadvantages of such systems are that the services are not offered or limited except for the standard processing options, the detailed information about the processing stage is not given, the difficulties in uploading and/or retrieving large volumes of data depending on the speed of internet connection (problems such as delays and outages) and the inability to access the system when updates are being made or problems occur.

Detailed information on the subject and application results from different measurement scenarios (such as static/kinematic mode, use of GPS and other satellite systems) are given in Ghoddousi-Fard and Dare, (2006); Tsakiri, (2008); Geng et al., 2010; El-Mowafy, (2011); Anquela et al., (2013); Guo, (2015); Abdallah and Schwieger, (2016); Dabove et al., (2016) and Malinowski and Kwiecień, (2016).

In this study, two of the popular online processing services, namely, CSRS-PPP and magicGNSS-PPP, were used to estimate PPP-derived coordinates. A brief overview of the services used in this study is given as follows. More detailed and up-to-date information on services can be accessed from the web page of the relevant service.

***i-)* Canadian Spatial Reference System Precise Point Positioning (CSRS):** In 2003, the CSRS-PPP service, operated by Geodetic Survey Division of Natural Resources Canada (NRCan), was developed. This free of charge online-PPP service allows the evaluation of single or dual frequency GNSS data in static or kinematic modes. Collected GPS and

GLONASS data can be evaluated with this service. Users need to load the RINEX data through the web-interface and choose some processing options (such as static/kinematic processing mode, NAD83 or ITRF08 reference system selection, and if required ocean tidal loading file for coastal region applications). Centimetre to decimetre-level of accuracy can be obtained depending on the frequency (single or dual frequency), GNSS system (GPS and/or GLONASS) and measurement mode (static/kinematic) selections. In kinematic mode, CSRS service uses forward-backward processing strategy. After the data uploaded the service, PPP-derived coordinates are calculated using best available precise satellite orbit and clock data (Ultra-rapid, Rapid or Final) provided by IGS or NRCan. After a short time, the results are sent to the user's e-mail address. The results contain not only coordinate but also some additional information, which is an important resource for users to analyse the results. More detailed information about the service is available at https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php.

***ii-)* magicGNSS:** The magicGNSS online GNSS processing service, developed by GMV Aerospace and Defense Company in Spain, was launched in 2008. Static or kinematic data in standard RINEX format are evaluated using precise satellite orbit and clock products produced by IGS and GMV. To take advantage of the extended satellite availability, this service allows processing GPS, GLONASS, Galileo, BeiDou and QZSS system data with centimetre-level accuracy depending on the observation time. Users can upload their collected dual-frequency data using only a single GNSS receiver through the service web page or via e-mail. Multi-constellation online-PPP service of the magicGNSS is free of charge for non-licenced user. Pro-licensed users, who are charged for high fee yearly, have many additional properties. One of the most important of these properties is that pro-users can process collected data with GPS and GLONASS data as well as Galileo, BeiDou and QZSS satellite systems. When the process is completed by the service, information and statistics of the process including the reports and graphs are sent to the users by e-mail in a short time. More detailed information about the service is available at https://magicgnss.gmv.com.

4. PERFORMANCE ANALYSIS OF KINEMATIC PPP

In order to compare the positioning performance of different PPP data processing platforms, i.e. widely used scientific/commercial softwares and online processing services in terms of accuracy in a dynamic environment, a kinematic test was conducted at Obruk Dam Lake, in Çorum, Turkey in June of 2017 (Figure 1).

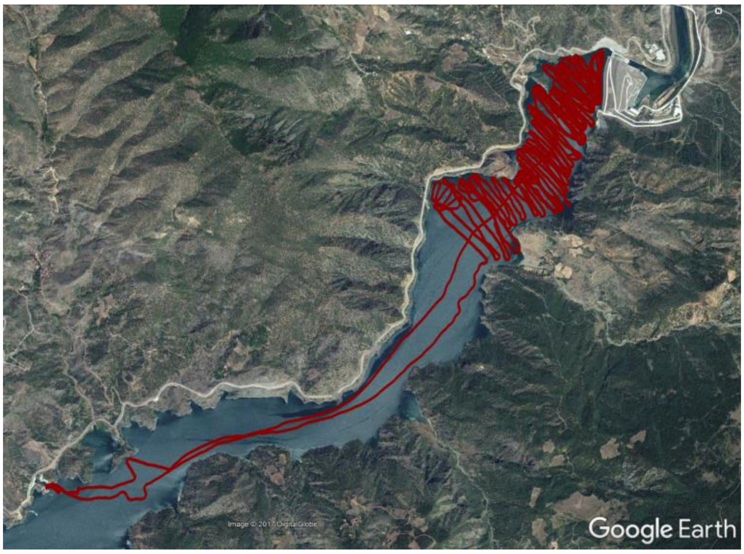


Figure 1. Trajectory of the Vessel

The test survey was started with static initialization by collecting the GNSS data within a couple of minutes on the shore. Then, the receiver and antenna were moved to the vessel and the kinematic test was started. Through the test, the data was collected for approximately 6 hours at 1-second data collection interval with an elevation mask of 10°. In this experiment, Trimble R10 multi-frequency/multi-constellation GNSS receivers were used. Positioning accuracy performance of the receiver is given in Table 1.

Table 1. Accuracy Performance of Trimble R10 Receiver (URL 1)

Static GNSS Surveying	**High-Precision Static**	
	- Horizontal	±3 mm + 0.1 ppm RMS
	- Vertical	±3.5 mm + 0.4 ppm RMS
	Static and Fast Static	
	- Horizontal	±3 mm + 0.5 ppm RMS
	- Vertical	±5 mm + 0.5 ppm RMS
Real-Time Kinematic Surveying	**Single Baseline <30km**	
	- Horizontal	±8 mm + 1 ppm RMS
	- Vertical	±15 mm + 1 ppm RMS
	Network RTK	
	- Horizontal	± 8 mm + 0.5 ppm RMS
	- Vertical	±15 mm + 0.5 ppm RMS

During the kinematic experiment, a second same type of GNSS receiver was occupied at a reference point on the shore and the GNSS data were collected through the measurement. The collected data at this station was used to calculate the precise known coordinates of vessel for each epoch (i.e. in order to obtain reference trajectory) with the carrier-phase-based differential method. The precise coordinate of the reference point was calculated with differential method by taking the Turkish RTK Continuously Operating Reference Stations Network (TUSAGA-Aktif) points as a base station. All GNSS data processing procedures were carried out with GrafNav GNSS Post-Processing Software. In order to improve the attainable accuracy, the software processes the data with forward and backward processing approach. After these processing;

- the known coordinates of the vessel (reference trajectory) with the post-processed relative method (Post Processing Kinematic-PPK),
- the coordinates of the vessel with PPP technique,

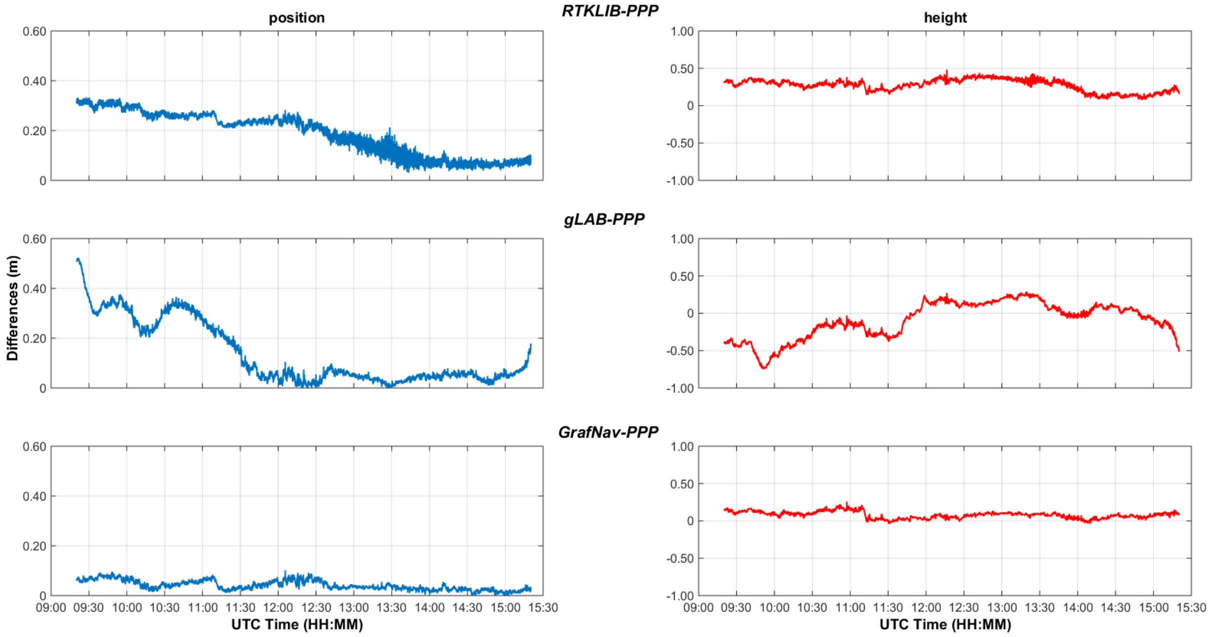
were calculated.

In order to investigate the performance of the online-PPP service, the collected data on the vessel was sent to the magicGNSS service via e-mail, and to the CSRS-PPP online-PPP service using its interactive web page. In both operations, kinematic mode was chosen. The PPP-derived coordinates and the related reports were retrieved in a short time via e-mail from the services. Table 2 summarizes the software and services used in all of the processing stage described above and the used options. As can be seen in the table the data collected from both GPS and GLONASS satellites, except RTKLIB and gLAB are used in all other platforms.

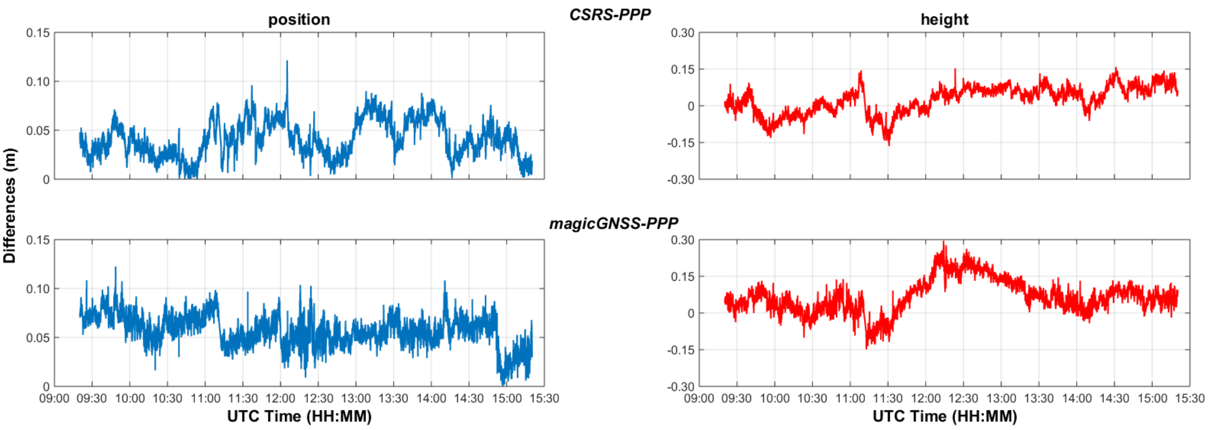
Table 2. The Used Processing Platforms and Options

	RTKLIB-PPP	gLAB-PPP	GrafNav-PPP	CSRS	magicGNSS
Service Name	RTKLIB: An Open Source Program Package for GNSS Positioning	GNSS-Lab Tool (gLAB)	GrafNav GNSS Post-Processing Software	Canadian Spatial Reference System – Precise Point Positioning	magicGNSS/PPP/ Precise Point Positioning Solution
Organization & Web Page	by Tomoji TAKASU Department of Maritime Systems Engineering Tokyo University http://www.rtklib.com	European Space Agency (ESA) and Research group of Astronomy & Geomatics Technical University of Catalonia (gAGE/UPC) http://gage.upc.edu/gLAB	WAYPOINT PRODUCTS GROUP / NOVATEL https://www.novatel.com/products/software/grafnav	Natural Resources Canada (NRCan) http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php	GMV Innovating Solution http://magicgnss.gmv.com/ppp
Reference Frame	ITRF08	ITRF08	ITRF08	ITRF08	ITRF08
Antenna Correction	IGS	IGS	IGS	IGS	IGS
Satellite Orbits and Clocks	Center for Orbit Determination in Europe (CODE) Final	Center for Orbit Determination in Europe (CODE) Final	Center for Orbit Determination in Europe (CODE) Final	IGS Final	GMV Rapid
Elevation Mask	10°	10°	10°	10°	10°
GNSS System	GPS only	GPS only	GPS+GLONASS	GPS+GLONASS	GPS+GLONASS
Used Software	RTKLib 2.4.2	gLAB_v5.1.1	GrafNav 8.70.5101	CSRS_PPP	MagicGNSS 5.3
Processing Mode	Kinematic	Kinematic	Kinematic	Kinematic	Kinematic
Frequency processed	Dual Frequency	Dual Frequency	Dual Frequency	Dual Frequency	Dual Frequency
Observation processed	Code and Phase	Code and Phase	Code and Phase	Code and Phase	Code and Phase
Solution Type	All epochs / Combined (Forward-Backward)	All epochs / Forward only	All epochs / Multi-Pass (Forward-Backward-Forward)	All epochs / Combined (Forward-Backward)	All epochs / Combined (Forward-Backward)
Processing Interval	1 second	1 second	1 second	1 second	1 second
Software Type	Desktop Open source Research Purpose	Desktop Open source Educational Purpose	Desktop Commercial	Online Processing Web-based	Online Processing Web-based

The coordinates of the vessel determined with scientific/commercial post processing software (RTKLIB, gLAB and GrafNav) and online-PPP services (CSRS and magicGNSS) were compared with those of differential solution epoch-by-epoch (PPK). Figure 2 illustrates the obtained differences in 2D position and ellipsoidal heights.



(a)



(b)

Figure 2. Differences between Known-coordinates (Differential Solution) and; Scientific/Commercial Software (a); Online GNSS Processing Services (b)

Some statistical information about the obtained differences are summarized in Table 3.

Table 3. Statistical Information about the Differences

Processing Platform		**2D Position (m)**	**Height (m)**
Scientific/Commercial Software			
RTKLIB	min.	0.03	0.07
	max.	0.33	0.48
	RMSE	0.21	0.28
gLAB	min.	0.00	-0.75
	max.	0.52	0.29
	RMSE	0.19	0.26
GrafNav	min.	0.00	-0.04
	max.	0.10	0.26
	RMSE	0.05	0.09
Web-based Online PPP Processing Services			
CSRS	min.	0.00	-0.16
	max.	0.12	0.16
	RMSE	0.04	0.06
magicGNSS	min.	0.00	-0.15
	max.	0.12	0.30
	RMSE	0.06	0.10

When the results given in Fig. 2 and Table 3 are examined, it is seen that the online services generally produce better accuracy than the scientific/commercial software. For scientific/commercial software group, the best result was obtained from GrafNav software, where the difference for 2D position reach to 10 cm as a maximum, while the difference for height component varies between -4 cm and 26 cm.

The results from Fig. 2 and Table 3 also show that, althoght RTKLIB produced better results than the gLAB, they were generally able to achieve 3D positioning within several dm level of accuracy. When the used options through the processing stage were investigated (Table 2), it is clearly seen that RTKLIB and gLAB software was processed only GPS data whereas GrafNav was used combination of GPS and GLONASS. In addition to this, gLAB estimate the PPP-derived coordinates with only forward processing while the others were processed the collected data with forward and backward processing strategy. All these factors affect the processing performance and PPP-derived coordinates were obtained from RTKLIB and gLAB software with lower accuracy.

When the results obtained from the online services are considered, it can be seen that the positions from both services have almost the same 2D and height positioning accuracy at the level of one dm or better. The height accuracy was obtained slightly worse than the position component and the difference were found between -16 cm and +16 cm for CSRS and -15 cm and +30 cm for magicGNSS service.

5. CONCLUSION

In this study, the accuracy performance of PPP technique by processing of kinematic data with scientific/commercial software and web-based online GNSS processing services are examined. The results showed that under dm level of accuracy can be achieved with the PPP technique in a dynamic environment easily, quickly and cost-effectively. The obtained accuracy proves that the PPP technique can be used many marine surveying applications.

On the other hand, when the PPP is chosen as a positioning technique for engineering or similar projects, it is highly recommended that the results must be analysed and interpreted very carefully. It should be kept in mind that, using the results without any analysis may cause a big mistake in some cases. Therefore, the results could be checked for instance by evaluating the same data sets on different platforms.

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BIOGRAPHICAL NOTES

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