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Examining PPP accuracy in relation to altitude

Emre Akman[*1], **Veli İlçi**[1]

[1]Ondokuz Mayis University, Engineering Faculty, Department Geomatics Engineering, Samsun, Turkiye

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Abstract

Online PPP services are increasing daily due to their user-friendly interfaces, quick turnaround times, the ability to evaluate data from a single GNSS receiver, and their cost-free nature. However, the veracity of the data provided by these services needs to be verified. This study examined the position and height accuracy variation provided by PPP services based on benchmark point altitudes. For this purpose, seven measurement points were established every 200 meters, starting from the sea level. Four-hour static GNSS observations were carried out at each point, and these data were first evaluated with the static post-processing method to obtain the known positions of the points. The static observations were then submitted to the popular online PPP services Trimble-RTX, AUSPOS, and CSRS-PPP, and the received position and height data were compared to the point's known coordinates. When the results were analyzed, it was found that changes in the position data were in the order of cm, while changes in the height data were in the order of 1-2 dm, depending on the altitude of the measurement point.

1. Introduction

Satellite-based positioning systems are evolving with technological developments. The first global positioning system, GPS (Global Positioning Systems), was first used for military purposes. Increasing demands from civilians and the emergence of broad application areas have made satellite systems available for all communities. Following these developments, the concept of global navigation satellite systems (GNSS) emerged as many countries established their positioning systems (GLONASS, GALILEO, BeiDou, QZSS, IRNSS) (Alkan, 2015). Because the absolute positioning approach, which enables position determination with a single GNSS receiver, cannot deliver the required position accuracy, the usage of relative positioning methods has risen.

The developed real-time kinematic (RTK) solution technique uses rover and reference GNSS receivers and provides cm-level position accuracy with an initialization time of a few seconds. The positioning accuracy of this technique varies depending on the base length between the rover and the reference receivers. Position accuracy declines as base length increases due to tropospheric, ionospheric and satellite orbit errors. In addition, carrier phase ambiguities cannot be eliminated sufficiently on long bases (>20km) (İlçi, 2019). Calculated corrections are transmitted through an internet connection or radio link. When correction information is sent via a radio-link connection, the base length is limited to 10-20 km, but this range reaches up to hundreds of km when transmitted via the internet (Alçay vd., 2021).

Due to these drawbacks in the RTK technique, a network-based RTK (NRTK) technique has been developed with continuously operating reference stations (CORS). Today, NRTK systems established by many countries and organizations are actively operating. Correction data is generated in each NRTK system by simulating orbital and atmospheric errors, yielding position data down to the centimeter level (Yurdakul, 2021). In addition to its many advantages, NRTK has disadvantages, such as initial installation cost, complex software and hardware requirements and the need for a GSM connection (Alkan vd., 2020). The system becomes utterly unusable if the work area is outside the GSM operator's coverage (İlçi vd., 2016). With such drawbacks, users seek new, accurate, faster position information acquisition techniques.

The PPP (Precise Point Positioning) technique improves the data collected from only a single GNSS receiver with correction information derived from precise satellite orbit and clock data, products of organizations such as IGS, JPL, and CODE. This technique does not require a radio or internet connection. Position accuracy in the order of centimeters is achieved by processing the observation data gathered in static or kinematic modes with the correction information

* Corresponding Author

*(emre.akman.hrt.muh@gmail.com) ORCID ID 0009 – 0008 – 5369 – 4145
(veli.ilci£omu.edu.trl) ORCID ID 0000 – 0002 – 9485 – 874X

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supplied by the services. While the PPP technique offers several benefits, including low cost, easy usability, and position data in a global datum, it also has drawbacks, including long convergence times and access to precise satellite ephemeris data (Alkan, 2020).

In addition to PPP software such as GRAFNAV, PANDA, BERNESE, etc., used for post-process evaluation, there are web-based online services such as CSRS, AUSPOS, TRIMLE-RTX, OPUS, APPS, SCOUT, GAPS, magicGNSS, etc. (Özdemir vd., 2019). AUSPOS, OPUS, and SCOUT services determine the position with a relative method, whereas CSRS-PPP, APPS, GAPS, and magisGNSS services determine the position with an absolute method. Services that employ the absolute method calculate the corrections by obtaining sensitive satellite information from other services, such as IGS, while services that use the relative method make calculations based on IGS or local CORS station coordinates close to the study area (Alkan vd., 2017).

In this study, the accuracy of position and height coordinates from widely used online PPP services were investigated depending on the altitude of the measurement points. Static observation data collected from benchmark points with different altitudes were submitted to TRIMBLE-RTX, AUSPOS, and CSRS-PPP services, and the delivered coordinates were compared with static post-processing outcomes.

2. Method

2.1. Trimble CenterPoint RTX post-processing service

Trimble's CenterPoint RTX (real-time eXtended) service was created in 2011 and made available in 2012 (Richter, 2019). This system monitors GPS, GLONASS, Galileo, BeiDou, and QZSS satellite signals with 120 network stations worldwide and transmits the collected data to the operation center. In order to get high-accuracy position information, real-time observation data and corrections obtained from satellite orbit, satellite time, and atmospheric errors are processed in the operation center using cutting-edge algorithms (Abdulla, 2017; Pirti vd., 2022).

Users can access the service without charge after registering. The process begins with writing the user's e-mail address, selecting the tectonic plate, and uploading GNSS observation data in an appropriate file format (RINEX, DAT, T01, T02, and Quark, etc.) to the service's web portal (Inyurt, 2020). Coordinates derived from GNSS observations are calculated in the ITRF2018 datum if observed before March 23, 2017, and calculated in the ITRF2014 datum if made after that date. Users receive result data through e-mail (URL 1).

2.2. AUSPOS Online GPS Processing Service

AUSPOS service, developed by Geoscience Australia, was first put into service in 2000. The service uses data from IGS and Asia-Pacific (APREF) reference stations closest to the measurement point (Alkan vd., 2017). The service can process at least 1 hour of data (recommended 2 hours) collected in static mode and at 30-second intervals with a dual-frequency GNSS receiver (Konakoğlu, 2020). This service uses the relative solution method (Erol, 2020).

Users do not need to register to utilize the service, which is entirely free to use. The process that uses Bernese software starts by entering the user's e-mail, antenna type and antenna height into the web interface, which allows uploading a maximum of 20 RINEX files (URL 2). Users receive corrected position data in ITRF2014 and Australian datum (GDA) via e-mail (Bahadur, 2014).

2.3. CSRS-PPP

Natural Resources Canada (NRCan) released the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service in 2003. The solution needs IGS and NRCan service data and satellite orbit and time information from the GPS and GLONASS satellite systems (Bülbül vd., 2022). The PPP-AR algorithm was updated to the latest version on October 20, 2020, replacing the previous solution method, which was the classical PPP method. (Bülbül vd., 2022).

Following registration, users can access the service, which is free to use (Yurdakul, 2023). For transaction with the CSRS-PPP service, the RINEX data file is uploaded, the coordinate system (NAD83 or ITRF) and the measurement mode (static or kinematic) is chosen, and the result files are sent to the user via e-mail. The results are available on the measurement epoch (URL 3). Single or dual-frequency GNSS phase measurement data can be processed (Alkan vd., 2017).

2.4. The site selection and data collection

A high-sloping route was determined as a study area in the Atakum district of Samsun, Turkiye. Seven benchmark points with approximately 200 m altitude differences were located along this route, which began at sea level. The locations of the benchmark points and their approximate altitudes above sea level are given in Figure 1. Metal pipes were set up on ground benchmark points for this and future experiments. Point locations suitable for GNSS measurements have been chosen in the study area that won't interfere with the GNSS signals. Four hours of static GNSS observations were conducted at each of the seven benchmark points to determine the known coordinates used for the comparison. GNSS observations were performed with Topcon HyperpPro multi-frequency receivers. GrafNet Post-Processing Software was used to specify the reference positions of the points. One-second RINEX data from the GNSS observation duration of SAM1, SINP, VEZI, and BOYT reference stations in the TUSAGA-AKTIF (CORS-TR) system were used in the Static Post-Processing operations. As a result of processes, high accuracy positions of 7 measurement points were defined in the ITRF96 datum and 2005 measurement epoch. In order to assess the accuracy of the coordinates obtained from online PPP services, they were converted into the ITRF96 datum and 2005 epoch and compared with the reference coordinates.

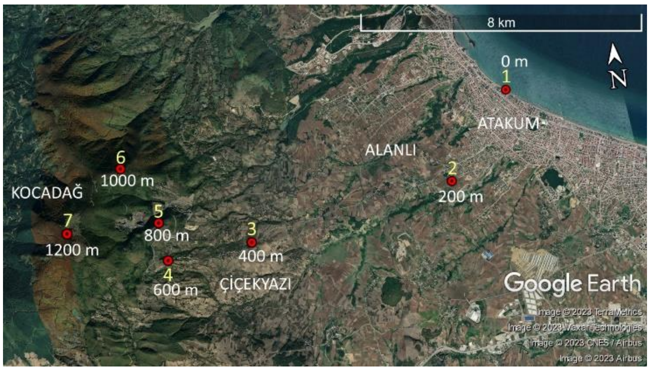

Figure 1. The location and attitudes of benchmark points

3. Results

The number and usage of online PPP services is increasing day by day. The present investigation examined the relationship between point altitude and the coordinate accuracy provided by PPP services. In this study, the use of Trimble CenterPoint RTX post-processing service, AUSPOS Online GPS Processing Service, and Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) services, all of which have been utilized in numerous academic studies, were preferred.

The 2D position errors of the coordinates supplied by PPP services are displayed in Figure 2. At each benchmark point, three PPP services offered less than 8 cm of error in 2D. The average errors were determined as 5 cm, 5 cm and 4 cm for Trimble, AUSPOS and CSRS services, respectively. However, the position errors gradually increase from point P1, which is closest to sea level, to point P7, which is at the highest altitude.

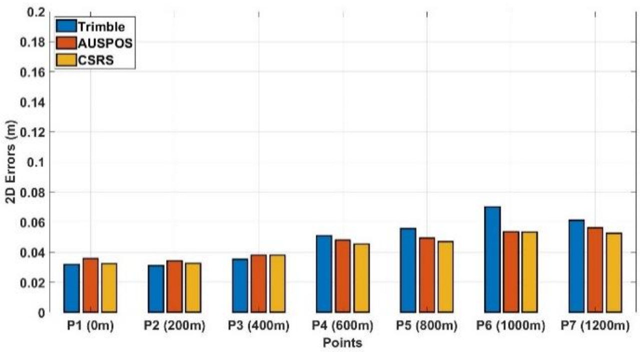

Figure 2. 2D positioning errors

The height errors of the results supplied by the PPP services for seven benchmark points at various altitudes are displayed in Figure 3. Contrary to 2D positioning accuracy, the height errors reach up to 2-dm level. Average height errors are 6 cm in the Trimble service, 6 cm in the AUSPOS service and 12 cm in the CSRS service. Notably, all three PPP services provide 1 cm accuracy at the zero altitude point. Furthermore, there is a noticeable increase in height error values with altitude, especially for the CSRS service.

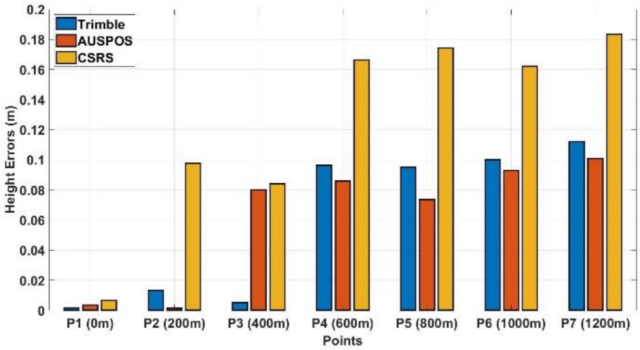

Figure 3. Height errors

4. Conclusion

In this study, the changes in position and height accuracies provided by online PPP services, depending on the altitude of the measurement points, were investigated. One of the main limitations of the use of these services is that the user cannot obtain the desired datum, epoch, or projection information of the output coordinates of the PPP service. Services generally provide results only in the ITRF14 or ITRF20 datum and measurement epoch, and users have to transform this data to the desired datum, epoch, and projection system.

As altitude was increased, a slight increase in 2D position errors was observed in this study. The height errors are observed to reach a 2-dm level and grow noticeably with increasing altitude above sea level. In particular, it has been determined that the height errors provided by the CSRS service are at the highest level. Consequently, it has been noted that point height data acquired from PPP services has less reliability.

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