Advanced Geomatics

http://publish.mersin.edu.tr/index.php/geomatics/index

e-ISSN: 2791-8637

Examination of the Performance of Precise Point Positioning Technique with Real-Time Products on Smartphones

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Keywords

Smartphone,
Single-Frequency,
GPS,
RT-PPP.

Research Article

Received : 29.12.2022
Revised : 09.03.2023
Accepted : 20.03.2023
Published : 31.03.2023

Abstract

This study evaluates the performance of a single-frequency GPS (Global Positioning System) positioning technique under real-time conditions using a smartphone. To assess the performance of the smartphone, GPS observations were recorded with the Geo++ RINEX Logger application on a Xiaomi Redmi Note 8 Pro and compared with measurements taken using a geodetic-grade CHC I80 GNSS receiver. Raw observation data were processed using Real Time-Precise Point Positioning (RT-PPP) technique with real-time satellite orbit and clock correction products produced by 4 different analysis centers (IGS, CNES, JAXA and Wuhan University). According to the results, it was seen that 4 different solutions made with only-GPS observations were consistent with each other both horizontal and vertical at millimeter level. In addition, an improvement of 89% to 98% was achieved in the root mean squared errors (RMSE) after convergence. Overall, this study demonstrates the potential of using single-frequency GPS observations on smartphones for real-time precise point positioning, which could have important applications in various fields including surveying, navigation, and location-based services.

1. Introduction

Advancements in satellite constellations, modernized signals, and positioning theory and algorithms have led to an increase in studies on geodetic-grade and low-cost GNSS receiver/antennas, including those integrated into smartphones (Zhang et al. 2021; El-Mowafy et al. 2020). Although early smartphones only provided position information using single-frequency and single-constellation satellites, the release of Android N (Nougat=Version 7) in 2016 enabled users of Android-based smartphones to access raw GNSS data, marking a significant milestone in precise positioning studies (Zhang et al. 2021; El-Mowafy et al. 2020; Xu et al. 2020). As a result, smartphones have become a focus of precise positioning studies due to their widespread usage and portability (Zhang et al. 2021; El-Mowafy et al. 2020; Xu et al. 2020).

Early studies identified GNSS antenna quality and cycle slip as the main issues affecting precise positioning using smartphones (Banville & Diggelen 2016). Subsequent studies evaluated the quality of raw measurements and position accuracy using linear polarized and external GNSS antennas with the Huawei Mate 9 smartphone (Siddakatte et al. 2017). However, until 2018, single-frequency GNSS observations were used for positioning, navigation, and timing applications on smartphones.

In 2018, Xiaomi introduced the Mi8 smartphone, which could collect dual-frequency GNSS raw observation data, enabling the evaluation of precise positioning performance using different techniques such as Real-Time Kinematic and Precise Point Positioning (Chen et al. 2019; Liu et al. 2021; Odolinski & Teunissen 2019; Robustelli et al. 2019; Wu et al. 2019). Although smartphones are low-cost and portable, they are sensitive to the multipath effect due to the GNSS antenna/chip used. GNSS receiver/antennas designed to minimize the multipath effect have advantages over the antenna/chip(s) used in smartphones. Moreover, the GNSS antenna/chip structure used in smartphones can cause interruptions in carrier-phase observations, which are widely used for high positioning accuracy (Paziewski et al. 2019; Zangenehnejad & Gao 2021).

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Cite this;

Pehlivan, H., Karadeniz, B. & Arı, B. (2023). Examination of the Performance of Precise Point Positioning Technique with Real-Time Products on Smartphones. Advanced Geomatics, 3(1), 33-39.

Recently, studies on point positioning using the Precise Point Positioning (PPP) technique with a single GNSS receiver under real-time conditions have gained momentum. This technique eliminates the need for a simultaneous reference receiver, network, or infrastructure compared to previous methods (Hosseini & Teunissen 2020). Along with the dual-frequency raw GNSS data collection capability of smartphones, PPP-based point positioning performance has been evaluated in both static and kinematic modes, achieving decimeter-level accuracy in static mode and a few meters in kinematic mode (Elmezayen & El-Rabbany 2019; Kulikov et al. 2019). In this study, we collected single-frequency GPS raw observations using a smartphone and a geodetic-grade CHC I80 GNSS receiver/antenna and evaluated their performance using the Real-Time Precise Point Positioning (RT-PPP) method.

2. Method

This study includes the RT-PPP technique based on only-GPS code and phase observations. In this context, the equations can be written as:

$$P_r^G = \rho_r^G + c.\delta t_r - c.\delta t^G + T_r^G + I_r^G + m_r^G + \varepsilon_{r,P}^G \tag{1}$$

$$\Phi_{r,j}^G = \rho_r^G + c.\delta t_r - c.\delta t^G + \lambda N_r^G + T_r^G - I_r^G + m_r^G + \varepsilon_{r,\Phi}^G \tag{2}$$

In these equations, the subscript r represents the receiver, while the superscript G represents the GPS satellite; The pseudorange and carrier-phase in P and Φ length units, respectively; ρ is the geometric distance; c is the speed of light in vacuum, δt_r and δt^s are receiver and satellite clock corrections, respectively; T_r^s indicates tropospheric delay along the signal path; I_r^s is the ionospheric delay along the signal path; λ is the carrier-phase wavelength; N_r^s is the initial phase ambiguity; m_r^s and ε_r^s represent the multipath and noise of the code and phase observations, respectively.

3. Results and Discussion

In this section, both the geodetic GNSS receiver/antenna and the android-based smart phone's information and observation datasets used in the experiments are introduced. In addition, the observations collected on the GNSS receiver/antenna(s) are shown with the RT-PPP method. Finally, the results of the positioning performance of the smartphone are presented using different GPS satellite orbit and clock products.

3.1. Experiment Design and Data Processing

In this section, the raw data collected in the experiments and their processes are mentioned. In the experiments, GNSS observations were made at 1 Hz sampling interval using CHC I80 GNSS receiver and Xiaomi Redmi Note 8 Pro model smartphone. Experiments were carried out in Gebze Technical University, Geomatics Engineering Department in November 2022 and lasted approximately 1.5 hours. The experimental setup is shown in Fig.1. GPS/GLONASS observations were collected in the experiments. However, the process was made with only-GPS observations.

Figure 1. The experimantal setup.

In the process steps, processes were carried out with the PPP technique by using the satellite orbit and clock correction information provided by 4 different analysis centers produced under real-time conditions. The first of these products, RTS products (IGS01/IGC01, IGS02 and IGS03 etc.) offered to the user under real-time conditions by the IGS analysis center, include satellite orbit and clock corrections by providing a continuous broadcast ephemeris stream. Thus, real-time applications, such as atmospheric water vapor measurement, remote sensing applications, hydrographic measurements, intelligent transportation systems, early warning systems, rapid hazard assessment and structural health monitoring, to obtain real-time precise satellite orbit and clock information, critical to its accuracy. However, since there were no processes during the experiment, a PPP-based solution was realized by obtaining satellite orbit and clock correction information from the CDDIS (The Crustal Dynamics Data Information System) archive, where the IGC01 broadcast stream was recorded. In a similar role to a secondary product, IGS-RTS, satellite orbit and clock correction products for GPS and GLONASS are routinely provided by the CNES (National Center for Space Research). The feature of CNES solutions is that the technique called undifferenced ambiguity solution is applied (Laurichesse et al. 2014). Thus improving the actual quality of the clocks for IGS-RTS. The use of these clock products allows for ambiguity resolution at the user receiver, achieving 1 cm horizontal precise point positioning accuracy. Satellite orbits and clocks created in real time are available in the CNES archive as sp3, clk and bia files a few minutes after midnight according to UTC (Coordinated Universal Time). Existing products are useful for post-process PPP software, but for users who want to test in real-time conditions. Therefore, PPP-based solutions have been realized with CNES real-time satellite orbit and clock products offered by the National Center for Space Studies. On the other hand, JAXA (Japan Aerospace Exploration Agency) has developed a precise GNSS orbit and clock prediction system called MADOCA (Multi-GNSS Advanced Demonstration tool for Orbit and Clock

Analysis). Using MADOCA products, user position can be calculated precisely with PPP technique. Also, since JAXA provides Real Time MADOCA product, this product was used for the third process. Finally, PPP-based solutions were realized with real-time satellite orbit and clock correction information produced by Wuhan University.

For these solutions, processes were carried out using the raw observation data recorded through the Geo++ Logger application of the Xiaomi Redmi Note 8 Pro model Android-based smartphone. In order to evaluate the positioning performance of the smartphone, a PPP-based solution was realized by using the raw GNSS observation data collected with a Geodetic-grade GNSS receiver and precise satellite orbit and clock correction products (Final product) produced by Wuhan University. The process steps of this technique in the experiments are shown in detail in Fig. 2 (Karadeniz et al. 2023). In this study, rtkpost application module of RTKLIB demo5_34a software, which is an open source software package for all solutions, was used.

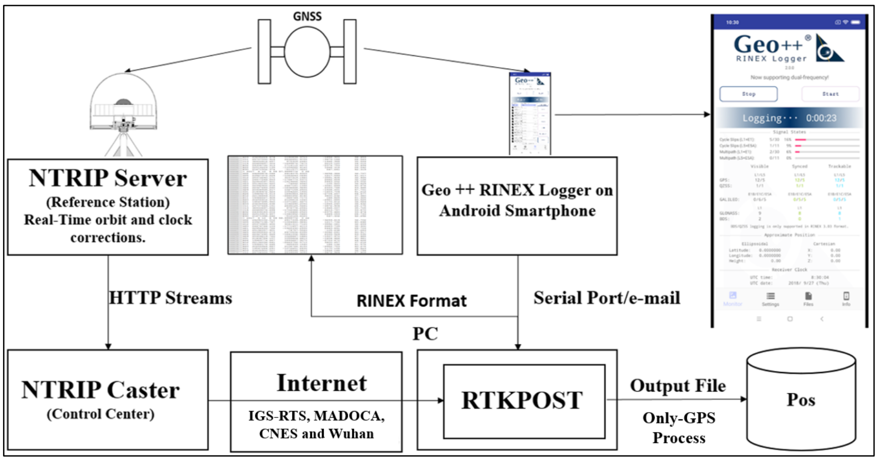

Figure 2. Schematic view of the RT-PPP method.

3.2. Positioning Performance with RT-PPP Method

In this section, raw GPS observations obtained from Xiaomi Redmi Note 8 smartphone are processed with RT-PPP technique in static mode, together with 4 different satellite orbit and clock information produced in real-time conditions. In the study, single-frequency GPS solutions were evaluated. In this context, a static mode RT-PPP solution was made using a single geodetic-grade GNSS receiver (CHC I80) to fairly evaluate the positioning performance of smartphones with single-frequency GNSS observations. Fig. 3 shows the epoch differenced time series of the solutions generated from both the geodetic-grade GNSS receiver and the smartphone throughout all experiment. In addition, statistical histograms of the epoch differenced obtained from the smartphone are given by taking the solutions obtained with the geodetic-grade GNSS receiver as reference. In the solutions of the referenced GNSS receiver, the Final product, which is precise satellite orbit and clock correction products and produced by Wuhan University, was used. The first line of the Fig. 3 shows the epoch differenced time series of the north, east, and up components, respectively, based on only-GPS observations.

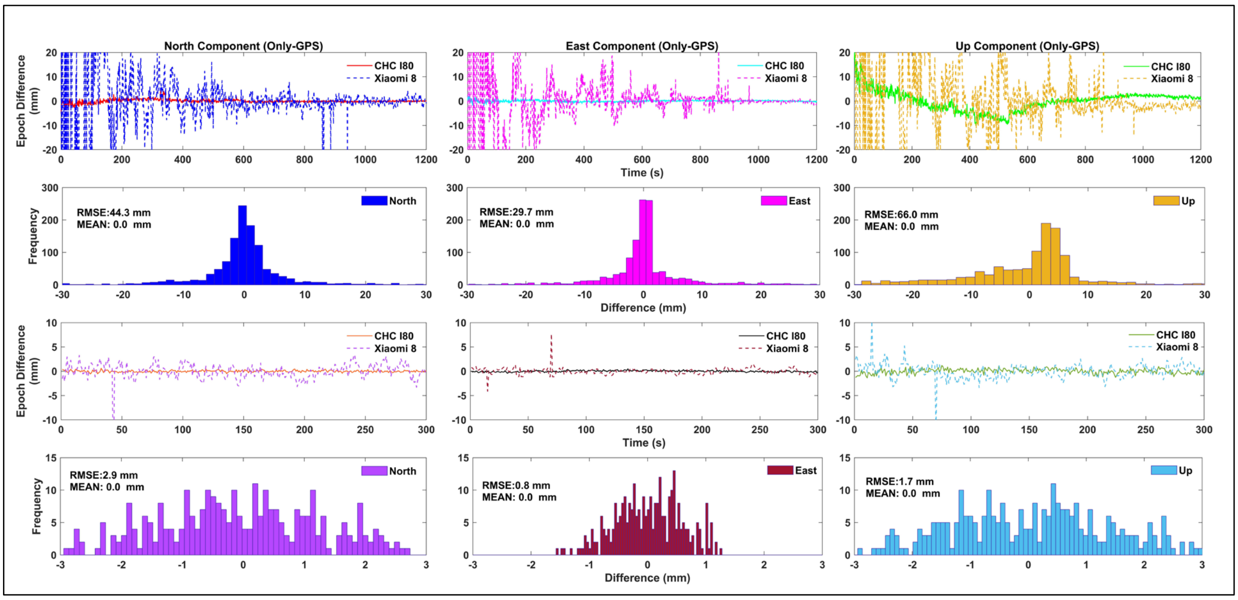

Figure 3. Epoch differenced time series and histogram distribution obtained using IGS-RTS products throughout the experiment and after convergence.

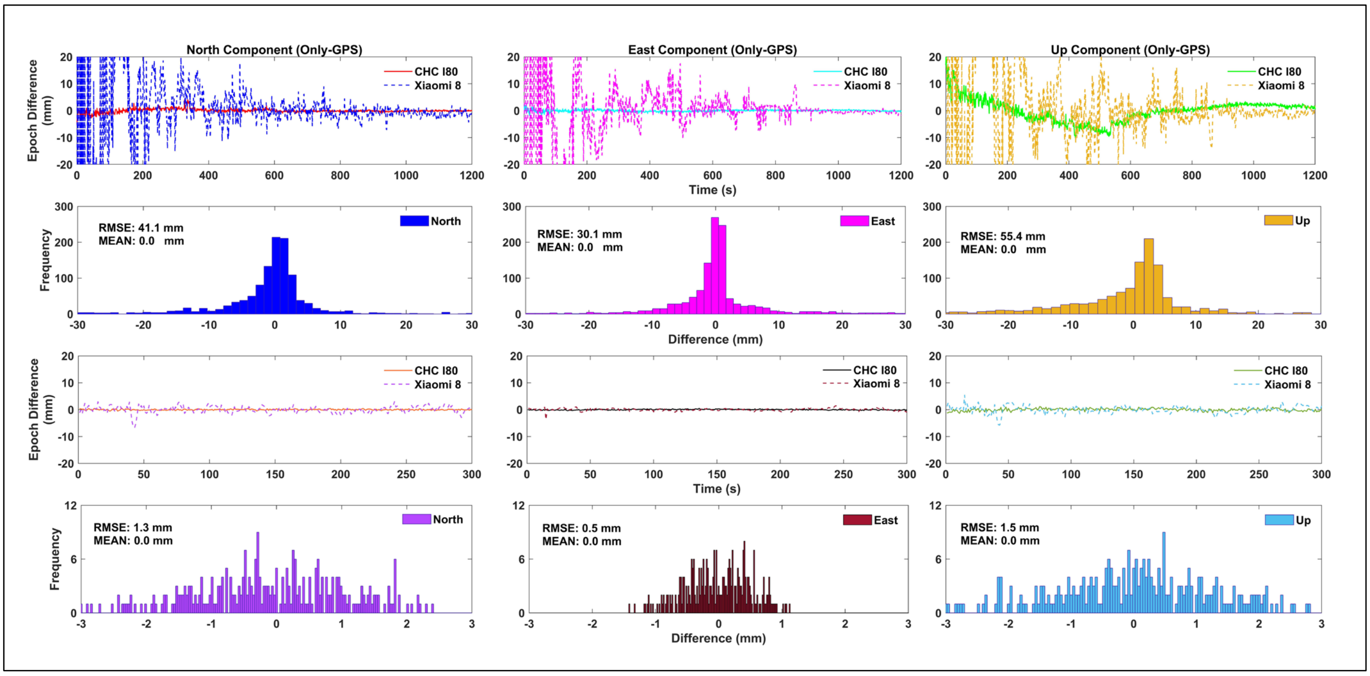

Figure 4. Epoch differenced time series and histogram distribution obtained using CNES products throughout the experiment and after convergence.

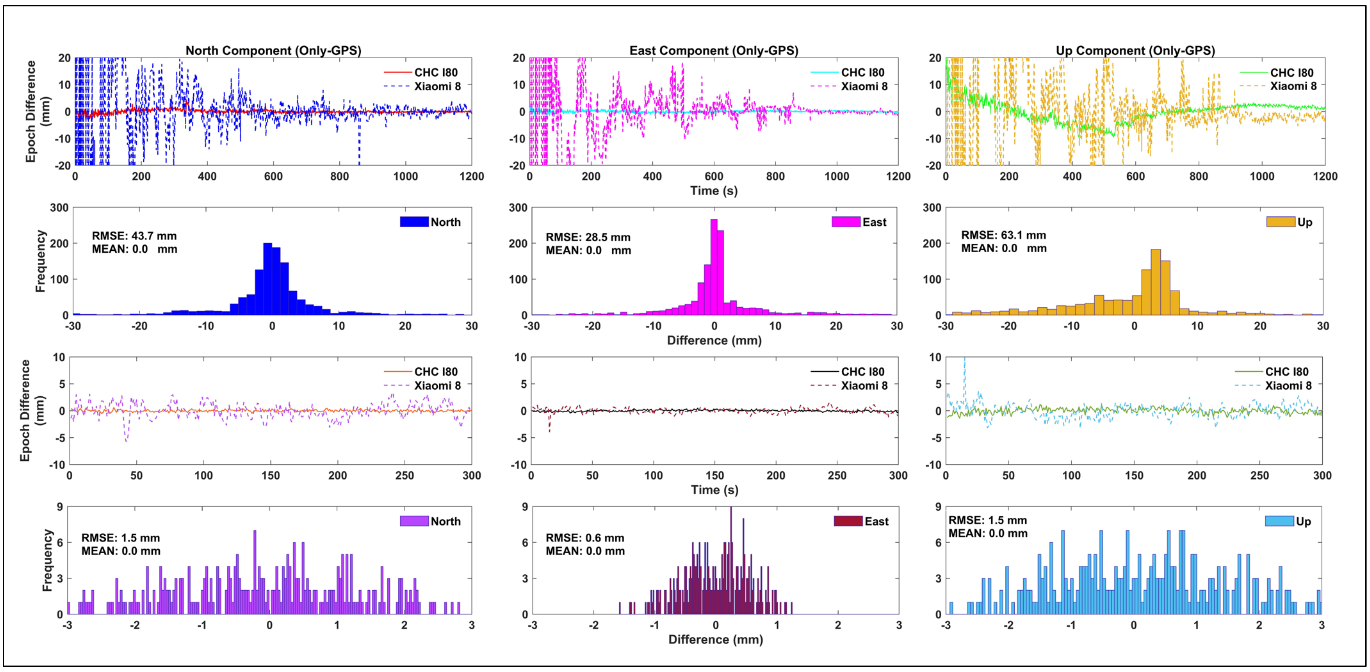

Figure 5. Epoch differenced time series and histogram distribution obtained using MADOCA products throughout the experiment and after convergence.

In the second line of the Fig. 3, the RMSE values and histogram distributions of the epoch differenced produced from the Xiaomi 8 smartphone are given in three different components, according to the geodetic-grade GNSS receiver referenced using the Final products produced by the Wuhan university. In the 3rd line of the Fig. 3, unlike the first line, the 300-second epoch differenced time series obtained after convergence is shown for both the smartphone and the geodetic-grade GNSS receiver. The positioning performance of the smartphone after convergence is applied as in the 2nd row of the Fig. 3, and the RMSE values and histogram distributions of the three different components are presented in the 4th row. According to the results, obvious fluctuations were observed in the time until the convergence time due to the integer phase ambiguity due to the nature of the PPP technique. In addition, the duty cycle technique required to preserve the battery life of the smartphone used in the experiment seems to reduce the quality of the measurements recorded by the smartphone. The absence of GPS observation data in each epoch leads to a longer convergence time for solutions. These gaps found in the GPS observations were corrected by interpolation. During all experiment, cycle slip is observed in the solutions synchronized from the smartphone. The signal received by the chipset causes cycle slip for many reasons. The most common of this problem is caused by objects blocking the signal from the satellite from reaching the chipset. But the experiments were carried out on the roof of the building in the open sky. When the observations in the experiments were examined, it was interpreted that the cycle clips occurred due to the low signal-to-noise ratio of the GNSS chipset in the smartphone. Considering the PPP-based solutions produced from both receivers, the average number of GPS satellites participating in the solution is higher in the geodetic-grade GNSS receiver. This is an important criterion that affects the positioning accuracy of the smartphone. According to the positioning accuracy of the smartphone obtained using IGS-RTS products throughout all experiment, it is 53.3 mm in the horizontal component and 66 mm in the vertical component. This is 3 mm for the horizontal component and 1.7 mm for the vertical component after convergence. After convergence, an improvement of 95% for the horizontal component and 97% for the vertical component is observed in the time series in which the epoch difference is taken. It will become popular for many applications in smartphones, thus shortening the convergence time to improve positioning accuracy in single-frequency Android-based solutions. Fig. 4, Fig. 5 and Fig. 6 show a similar situation using products produced under real-time conditions from CNES, MADOCA, and Wuhan, respectively. When the effect of different real-time products on positioning accuracy on smartphones is examined, it is seen that there is an improvement between 89% and 98% in all solutions after convergence. In the solutions obtained using 4 different real-time products, the best result of positioning accuracy for both horizontal and vertical components was obtained by using CNES products. This is followed by MADOCA, IGS and Wuhan, respectively. However, when the RMSE values of 4 different solutions are examined, it is seen that there are differences at the mm level.

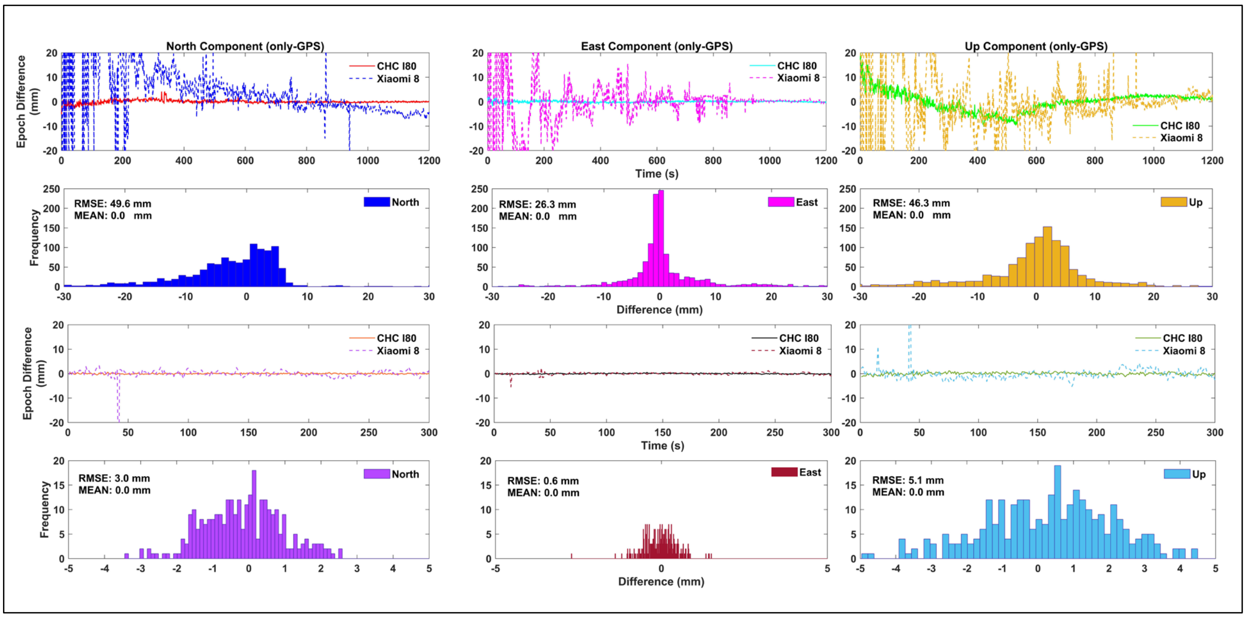

Figure 6. Epoch differenced time series and histogram distribution obtained using Wuhan products throughout the experiment and after convergence.

4. Conclusion

In this study, the positioning performance of single-frequency only-GPS observations collected statically with a smartphone was evaluated by RT-PPP technique. In the experiment, the data set collected with both the Xiaomi Redmi Note 8 smartphone and the geodetic-qualified CHC I80 GNSS receiver is solved with the PPP technique, which is a special case of absolute positioning. In order for the results to be evaluated fairly, solutions were obtained with the geodetic-grade GNSS receiver and the Final product, a precise satellite orbit and clock product produced by the Wuhan University. Raw observation data collected on a smartphone based on GPS observations were evaluated using 4 different real-time satellite orbit and clock correction products. According to the results, it has been seen that the solutions obtained with CNES products are more accuracy. However, the solutions obtained from IGS-RTS, MADOCA and Wuhan real-time products are in millimeters-level consistent with each other in both horizontal and vertical directions. After convergence, it is seen that there is an improvement between 89% and 98% for all 4 different solutions. Therefore, shortening the convergence time to increase the positioning accuracy of smartphones will increase the usability of smartphones for many applications. In addition, the features of the smartphone used in the analysis of the data are weaker than the smartphones used today. In future studies, it is considered to examine different combinations of dual-frequency satellites under different environmental conditions under real-time conditions. In addition, according to the method used, GNSS raw observation data will be evaluated in terms of positioning accuracy with the approach depending on the different signal-to-noise ratio as the weighting model. In addition, the usability of the developing smartphone technology in natural disasters in our country will be investigated.

Acknowledgement

The authors acknowledge Dr. Tomoji Takasu, developer of RTKLIB software (https://rtklib.com/), of the Tokyo University of Marine Science and Technology, Japan, for providing software.

Author contributions

Hüseyin Pehlivan: Data curation, Writing-Original Draft Preparation, Validation, Control and Validation
Barış Karadeniz: Conceptualization, Methodology, Software, Data curation, Writing, Visualization
Barışcan Arı: Investigation, Software

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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