Kufa Journal of Engineering
Vol. 15, No. 3, July 2024, P.P. 82-106
Article history: Received 12 January 2024, last revised 8 April 2024, accepted 19 April 2024

ASSESSING THE POSITIONAL ACCURACY OF RAW GNSS DATA FROM ANDROID DEVICES

Hasan A. Jaafar[1] and Jareer Mohammed[2]

[1] **Civil Department/Faculty of Engineering, University of Kufa, Najaf, Iraq,**
Email: hasana.alhusseini@uokufa.edu.iq

[2] **Civil Engineering Department, Wasit University, Kut, Iraq,**
Email: jareermohammed@uowasit.edu.iq

https://doi.org/10.30572/2018/KJE/150306

ABSTRACT

Smartphone devices have become the focus of attention of scholars dealing with GNSS measurements since May 2016 when Google stated using Android operating system version N that can access GNSS raw data. This opened the research door wide to process this data and analyse different issues in positioning by smartphones. Our study contributes to the assessment of GNSS data accuracy by evaluating various Android Application Programs (APPS) using Samsung Galaxy S9PLUS smartphone. While previous research has explored this topic, our study distinguishes itself through a comprehensive comparison of three APPS and two positioning techniques. By highlighting performance variations and considering multiple constellations, we provide valuable insights for smartphone GNSS users. Three different Apps were utilised: G-RitZ Logger, GnssLogger, and rinex ON. In addition, two GNSS positioning techniques were used for assessment: Post Processing Static (PPS) and Precise Point Positioning (PPP). The results revealed that GnssLogger obtain consistent readings in different scenarios. Therefore, GnssLogger is considered as the best logging GNSS data by smartphones. Moreover, accuracy is also discussed based on different constellations: GPS, GLONASS, and GALILEO. As expected, GPS results are the best compared to other constellations owing to availability and tracking priority for smartphone software. The best results obtained from GnssLogger with PPS technique and GPS system which has given RMS as 0.034 m, 0.171 m, and 0.383 m for E-W, N-S, and U-D axes respectively.

KEYWORDS

GnssLogger, smartphone positioning, RitZ Logger, rinex ON, PPP, PPS.

1. INTRODUCTION

The announcement of Google in May 2016, for accessing GNSS raw observations on mobile devices spurred a revolution in positioning, navigation, and timing (PNT) devices. The Android operating system version N ("Nougat" = version 7) defines Application Programming Interfaces (APIs) that allow users to access GNSS raw data through software classes (i.e., GnssClock and GnssMeasurement) of android location APIs (Banville and Van Diggelen, 2016). This opens possibility of determining precise positioning with smartphones by post-processing using externally produced GNSS corrections (Håkansson, 2018b).

Soon after, Google released Application Personal Program (APP) for capturing and recording GNSS observations named GnssLogger which can save GNSS raw data as text files (early version) or Receiver Independent Exchange Format (RINEX) (recent version) (Chen et al., 2019). This also motivated scholars to conduct research in this area.

In addition, in May 2017 the European GNSS agency published a white paper about using GNSS raw measurements on Android devices which provides detailed instructions for developers as well as the current research status in this respect (The GSA GNSS Raw Measurements Task Force, 2017). Furthermore, Broadcom announced in September 2017 the BCM47755 which is the first dual-frequency GNSS receiver chip (Dabove and Di Pietra, 2019b). In theory, smartphone GNSS receivers positioning accuracy can reach that of the geodetic receivers (Borio et al., 2016). Since then, a number of studies have been conducted to assess and analyse the capabilities of various Android devices in terms of accuracy and precision (Håkansson, 2018b, Chen et al., 2019, Dabove and Di Pietra, 2019a, Elmezayen and El-Rabbany, 2019, Fortunato et al., 2019, Gogoi et al., 2019, Li and Geng, 2019, Liu et al., 2019, Niu et al., 2019a, Robustelli et al., 2019, Specht et al., 2019, Szot et al., 2019, Wu et al., 2019, Aggrey et al., 2020, Dabove et al., 2020, Karki and Won, 2020a, Shinghal and Bisnath, 2021).

In recent years, the field of Global Navigation Satellite Systems (GNSS) has witnessed remarkable advancements, particularly in the domain of smartphone-based positioning. A plethora of studies have delved into the intricate interplay between constellation settings and parameters and their impact on GNSS accuracy, providing valuable insights into the factors influencing positional ground accuracy.

Håkansson (2018a) conducted an in-depth analysis of the multipath effects on raw GNSS observations collected by the Nexus 9 tablet. By leveraging GPS and GLONASS systems, Håkansson's study revealed crucial findings, demonstrating position accuracy of approximately 1 meter for scenarios with moderate multipath, while achieving sub-meter accuracy levels in low multipath conditions. Moreover, the research shed light on the influence of inter-system biases on precision distortion, underscoring the significance of comprehending constellation settings for precise positioning outcomes.

Zhu et al. (2020) ventured into real-time precise point positioning using the Xiaomi MI 8, a dual-frequency Android smartphone. Through their investigation encompassing multiple constellations including GPS, BDS, and Galileo, Chen et al. elucidated horizontal and vertical positioning accuracies of around 0.81 meters and 1.65 meters, respectively. This study underscored the pivotal role of constellation diversity in augmenting accuracy levels in smartphone-based GNSS applications.

Dabove and Di Pietra (2019b) explored Real-Time Kinematic (RTK) techniques with data from multi-constellations to assess Android device positioning accuracy. Their comprehensive analysis, comparing setups with geodetic receivers and smartphones, showcased achievements of several centimeters of accuracy with smartphone-based RTK. Furthermore, the research underscored the necessity of optimizing constellation settings to enhance positioning precision significantly.

Massarweh et al. (2020) meticulously evaluated the quality of various Android devices in controlled environments, leveraging an anechoic chamber to mitigate multipath effects. Through simulated signals from the GPS constellation, the study brought to light challenges in achieving ambiguity resolution, even under controlled conditions. This study highlighted the criticality of understanding constellation settings and their impact on GNSS performance.

Hu et al. (2023) delved into GNSS measurement errors collected by smartphones equipped with both embedded and external antennas. Their findings revealed significant disparities in noise levels between smartphone measurements and those from traditional geodetic receivers. Additionally, Li and Geng emphasized the importance of optimizing constellation settings to mitigate measurement errors and enhance accuracy outcomes significantly.

Niu et al. (2019b) proposed an innovative IMU-based pedestrian navigation algorithm to enhance RTK performance in urban areas using smartphones. Their groundbreaking study demonstrated remarkable improvements in robustness and adaptability to complex environments, underscoring the importance of optimizing constellation settings for accurate positioning in challenging scenarios.

Karki and Won (2020b) contributed insights into the power consumption of dual and single-frequency GNSS devices, offering valuable perspectives on the trade-offs between constellation configurations and power efficiency. Their research highlighted the imperative of optimizing constellation settings not only for accuracy but also for managing power consumption effectively in smartphone-based GNSS applications.

Moreover, recent studies by Mohanty and Gao (2023),Subedi and Pyun (2020) and Wang et al. (2023) have explored advanced signal processing techniques, machine learning algorithms, and optimization methods to further enhance GNSS positioning accuracy in smartphone applications. These studies offer innovative approaches for optimizing constellation settings and parameters, facilitating superior accuracy outcomes across diverse operational contexts.

By synthesizing insights gleaned from these studies along with existing literature, a comprehensive understanding of the intricate relationship between constellation settings and parameters and positional ground accuracy in GNSS applications is achieved. These findings provide invaluable guidance for optimizing accuracy outcomes across various operational scenarios.

Following this, this article aims to assess GNSS data collected by different Android Application Programs (APPS) in terms of position accuracy. Three different APPS are employed for data collection: G-RitZ Logger, GnssLogger, and rinex ON. In addition, two GNSS positioning techniques are used for assessment: Post Processing Static (PPS) and Precise Point Positioning (PPP). Moreover, accuracy is also discussed based on different constellations: GPS, GLONASS, and GALILEO. An open-source RTKlib processing software is employed to conduct the above processing.

In this paper, we aim to address the following inquiries: How to assess GNSS Apps data? What is the required time to converge to the optimum solution? What is the optimal solution to employ based on different constellation scenarios? And what is the utmost precision achievable in the optimal scenario?

2. TEST SETUP

For the experimental test in this research, the Samsung Galaxy S9PLUS smartphone is employed. Thanks to Broadcom BCM47752 GNSS Receiver chip, this device can collect GNSS data in form of carrier-phase, Doppler and pseudorange measurements on the L1 signal for GPS, GLONASS, BeiDou, Galileo, and QZSS.

Further, this device is operated by Android 10 (Android Q) OS, which manifests a great advance in terms of duty cycling. The duty cycling is known as an obvious limitation of precise positing by smartphones, which is used to turn on and off the power for the GNSS chip in the device for the purpose of the battery saving mode. This introduces clock discontinuities and breaks continuity between receiver and satellite, consequently, introduces cycle slips in the carrier-phase ambiguity measurements. Though this version of the Android OS, now it is possible to turn off the duty cycle. This can be done from the Developer options in the device setting **Error! Reference source not found.**.

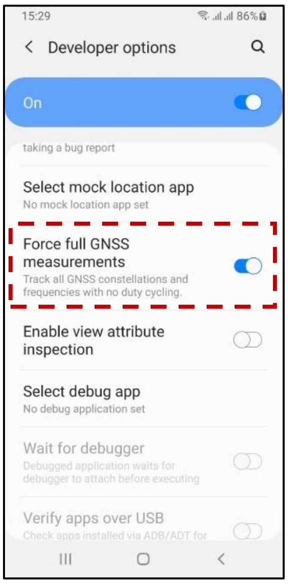

Fig. 1 Screen shoot for developer options setting of the Samsung Galaxy S9PLUS smartphone

For accuracy assessment, a known reference station is used, which is installed on the roof of the Remote Sensing building at the main campus of the University of Kufa **Error! Reference source not found.**. The reference station, situated atop a 2.5-meter steel tower, is located at coordinates [E=440726.368, N=3543939.450, elev.= 47.026, WGS 84/UTM zone 38N]. Hence, this location may have a favourable location due to no obstacles and no reflecting surfaces. However, However, this assertion may not accurately represent the actual circumstances due to

Fig. 2 The Reference Station in Remote Sensing Center

the characteristics of the smartphone GNSS antenna, which has a spherical gain pattern with similar gain in all directions in order to let smartphone users get GNSS position estimates regardless of the orientation of the device. Therefore, it is still susceptible to multipath errors caused by signal reflections from below the antenna.

3. MATERIALS AND METHODOLOGY

The smartphone GNSS raw measurements are collected by the android.location APIs with two classes the GnssClock and GnssMeasurement. Unfortunately, Android API does not provide a straightforward pseudorange (The GSA GNSS Raw Measurements Task Force, 2017), and logger Apps calculate GNSS time or pseudorange measurements. Therefore, there are probably differences in the quality of the output data from different logger Apps.

The concepts of GNSS solutions are based on the time of signal transmission and arrival. Each GNSS has its own reference time. The multi-GNSS receivers have the ability to track satellites from a different system and normally synchronise the reference time to only one system. Most of the smartphone devices, the GNSS are synchronised with GPS time reference. Theoretically, multiple GNSS constellations possibly increase positioning accuracy due to the increasing availability of satellites. However, time bias between the systems (Inter-System Bias, ISB) resulting from synchronization might degrade the position solution (The GSA GNSS Raw Measurements Task Force, 2017).

The prior knowledge of ISB might be transmitted in the navigation message, such as the GPS to Galileo Time Offset (GGTO) owing to Galileo's inter-system operability with GPS. Otherwise, the ISB is estimated as an additional unknown parameter in the position equation. For instance, if four constellations (GPS, GLONASS, Galileo, and BeiDou) are employed in the position solution, three ISBs between GPS and other systems (GLONASS, Galileo, and BeiDou) will add as unknowns to four basic unknowns (X, Y, Z, and clock offset). In this case, it is required at least seven satellites, rather than four satellites, for the positioning solution, consequently, Dilution of Precision (DOP) may decrease and that will lead to an increasing positioning error. Table 1 reveals the estimated accuracies and availabilities for different multi-constellation scenarios (ibid).

Hence, as previously mentioned, this research aims to assess the accuracy of GNSS data collected by different Android Application Programs (APPS). For this purpose, three Apps are employed:

1- **GnssLogger App:** This App is developed by Google and it is released shortly after the announcement of Google, in May 2016, as the interface for accessing GNSS raw observations on the mobile. The early version of this App can save GNSS raw observations as text files only. Therefore, in order to process data, it is required to change this file to

Receiver Independent Exchange Format (RINEX). However, the recent version (v3.03.1) can also prepare RINEX file so can be processed easily.

2- **G-RitZ Logger:** This App is developed by Information & Communication Lab, Ritsumeikan University. It is firstly released in May 2018. The output of this App is a RINEX file.

3- **Rinex ON:** This App is developed by Nottingham Scientific Limited as part of the FLAMINGO (Fulfilling enhanced Location Accuracy in the Mass-market through Initial GalileO services) project (https://www.flamingognss.com/). It is released in May 2019. This App also provides RINEX file as the output of GNSS measurement data.

3.1. Constellations

For this research, three GNSS constellations (GPS, GLONASS, and Galileo) have been used owing to that ISNA CORS point does not support the BeiDou solution on one hand, and adding the BieDou system has no real impact in terms of accuracy and availability Table 1 in the other hand.

Table 1. Accuracy and availability multi-constellation (The GSA GNSS Raw Measurements Task Force, 2017).

PVT configuration	Horizontal confidence level [meters]		
	68%	95%	Availability
GPS	13.36	25.51	97.79%
GPS + GAL	12.48	23.78	98.04%
GPS + GLO + GAL	11.24	21.57	98.30%
GPS + GLO + GAL + BEI	11.17	21.44	98.30%

3.2. Post-Processing

As long as our concern is a cost-effective way for GNSS positioning, it is required to avoid using commercial software for processing.Therefore, the open-source software RTKlib (http://www.rtklib.com/) is utilised for processing, developed by Tomoji Takasu from the Tokyo University of Marine Science and Technology in Japan. This software can give a solution for various positioning techniques for both real-time and post-processing approaches with GNSS's many constellations (GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS). For the purpose of analysis, two positioning techniques have been conducted in this paper:

1- Post-Processing Static PPS**:** or what is known as carrier-based double differencing. For differencing, it is required observation data from a known base station near the smartphone (10-20 km). Theoretically, this technique is the best way to assess possible obtained accuracy because most of the biases are mitigated during differencing. Therefore, its outcomes are considered as the best possible accuracy can be obtained.

Continuously Operating Reference Stations (CORS) point installed by National Geodetic Survey (https://geodesy.noaa.gov/CORS/) is employed. The selected point is (ISNA) /Iraq survey Najaf, which is about a few kilometers away from the Remote Sensing building.

2- Precise Point Positioning PPP: For this technique no need for differencing and consequently no need for base station. However, precise ephemeris as a precise satellite orbit and clock corrections are required to mitigate satellite-related errors. The reason of using this technique is that any observation with high noise will be omitted by RTKlib software before processing. This can be adjusted through setting the reject threshold of GDOP and kalman filter innovations (m) (**Error! Reference source not found.**) (Takasu, 2013). Therefore, it is a good way to assess the noise data of GNSS APPS, as the more observations used in the processing is the less noise data and better GNSS APPS.

On the other hand, precise ephemeris obtained from the multi-GNSS experiment (MGEX) have been used and published by CDDIS (The Crustal Dynamics Data Information System) (https://cddis.nasa.gov/archive/gnss/products/mgex/). The tropospheric delay has been estimated for ZTD (zenith total delay) and horizontal gradient parameters as Extended Kalman Filter (EKF) states, which can be done by RTKlib software. While for the ionospheric biases, the IONEX TEC grid data, downloaded also from CDDIS, has been employed. Furthermore, the other error sources such as the Earth's rotation, the satellite orbit eccentricity, and Earth tides have been eliminated by software using CDDIS products.

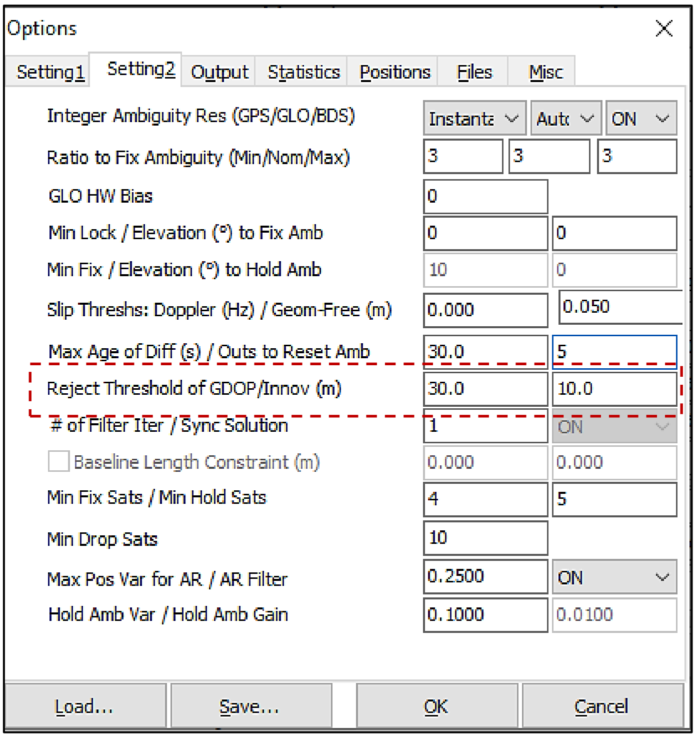

Fig. 3 Setting of RTKlib software

Based on above discussion, the proposed methodologies have been set as follows **Error! Reference source not found.**:

1- Applying PPP technique on GnssLogger, G-RitZ, and rinex ON data with all constellations, i.e., three processing. This can give general view about data noise for each Apps based on the utilised observations.

2- Same as Methodology 1 but alternatively applying PPS technique on GnssLogger, G-RitZ, and rinex ON data with all constellations. This mean conducting another three processing in order to determine the best possible accuracy for each Apps.

3- In order to assess the noise of the separated data for each GNSS system, PPP technique was applied for each Apps data for each constellation system GPS, GLONASS, and Galileo, i.e., nine processing.

4- Finally, to determine the best possible accuracy of each GNSS system, PPS technique is applied on Apps data for each constellation system GPS, GLONASS, and Galileo, i.e., nine processing.

Consequently, 24 processing proposed to be conducted in order to answer research questions.

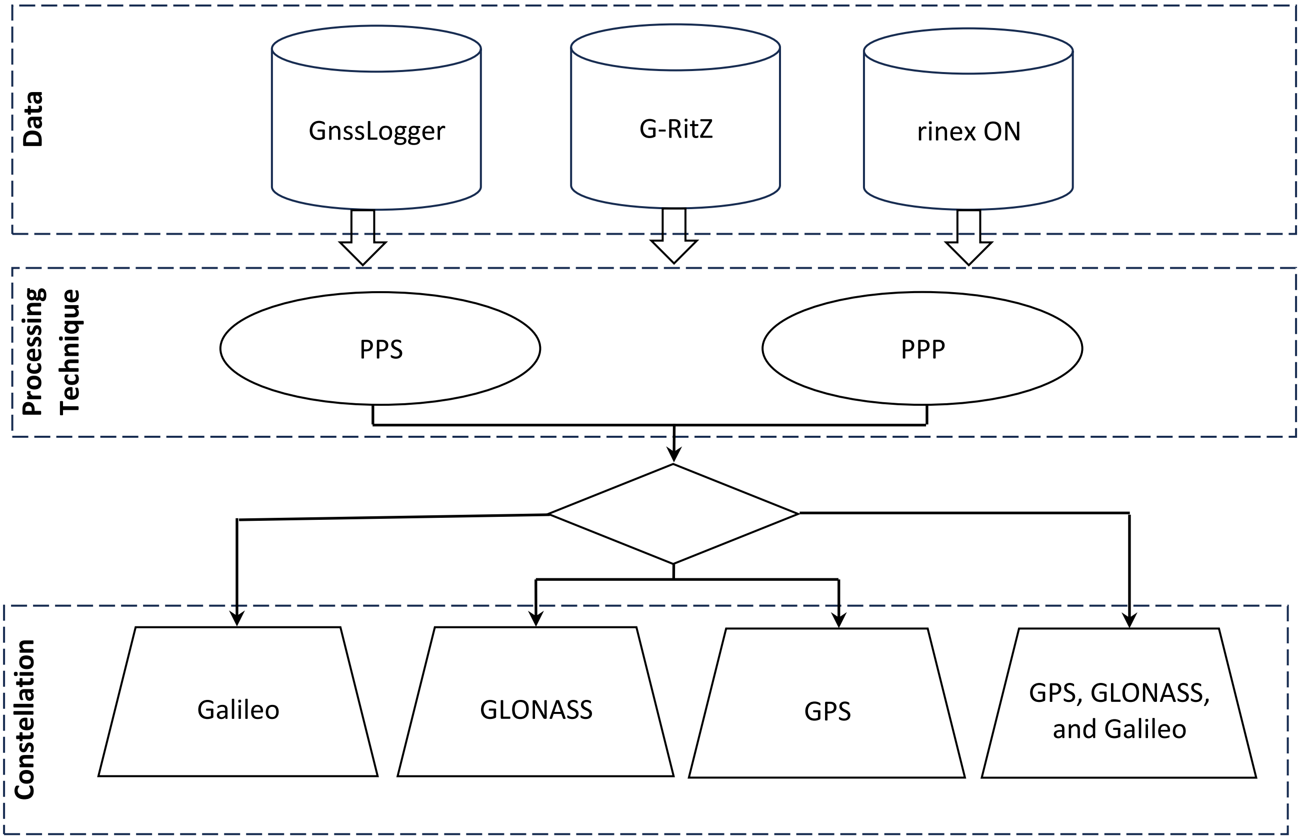

Fig. 4 The proposed work frame chart

4. RESULTS

The experimental test was conducted on 23/3/2022. For each logger Apps GNSS measurements were collected with a logging time of about 15 mins and an epoch interval of 1 second. It is suggested to assess accuracy in a short time (15 mins only) using a smartphone, in this case, is logical in real-life state. Then after, the precise ephemeris and all other required products mentioned in section 3 have been downloaded when they are available online. Firstly, the data has been processed in the PPP technique with all constellations for all logging Apps. The results of this process are listed in Table 2 and figures **Error! Reference source not found.** to **Error! Reference source not found.**. Due to the quality, the number of observations used for the solution is nearly all in GnssLogger and G-RitZ, 99%, and 98% respectively, whereas only 16% of observations were employed in Rinex ON. In addition, based on standard deviation (STD), the precisions of GnssLogger and G-RitZ data are much better than those of Rinex ON data. Coinciding with precision, the root mean square errors (RMS) for the horizontal position (E and N) in GnssLogger and G-RitZ are better than of Rinex ON, about a meter, sub-meter, and about two meters respectively. Surprisingly, the RMS of the vertical position in Rinex ON is better than of those in GnssLogger and G-RitZ. In General, it can be concluded the GnssLogger and G-RitZ are nearly consistent in terms of precision and accuracy. Whereas, the results of Rinex ON reveal maladjusted behaviour. Furthermore, figures **Error! Reference source not found.** to **Error! Reference source not found.** show no improvement in solution after the first five minutes, hence five minutes are enough to give the same or more accurate results.

Table 2 Test results of different Apps with PPP technique and all constellations.

App	GNSS	No obs.	E-W (m)			N-S (m)			U-D (m)		
			Avg.	STD	RMS	Avg.	STD	RMS	Avg.	STD	RMS
GnssLogger	GPS	480	4.325	0.026	4.325	3.306	0.045	3.306	3.737	0.487	3.768
	GLO	54	0.561	0.162	0.584	5.510	0.165	5.512	13.451	0.074	13.451
	GAL	46	0.838	0.038	0.839	2.500	0.034	2.500	14.417	1.038	14.454
	Multi	824	1.181	0.065	1.182	1.134	0.049	1.136	6.456	0.517	6.477
G-RitZ	GPS	535	1.970	0.065	1.971	0.692	0.122	0.703	9.341	0.157	9.342
	GLO	0	-	-	-	-	-	-	-	-	-
	GAL	0	-	-	-	-	-	-	-	-	-
	Multi	885	0.924	0.022	0.925	0.565	0.041	0.566	8.200	0.828	8.242
rinex ON	GPS	135	0.252	0.009	0.252	1.019	0.136	1.028	5.441	0.627	5.476
	GLO	0	-	-	-	-	-	-	-	-	-
	GAL	0	-	-	-	-	-	-	-	-	-
	Multi	144	2.830	0.354	2.852	2.122	0.485	2.176	0.145	0.494	0.513

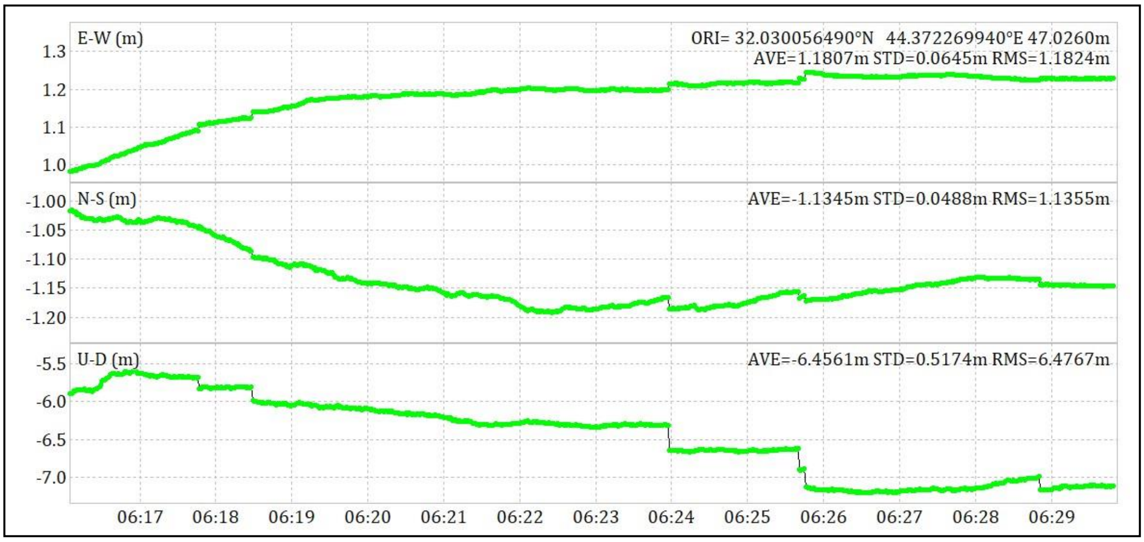

Fig. 5 Accuracy of GNSS data collected by GnssLogger with PPP technique and all constellations.

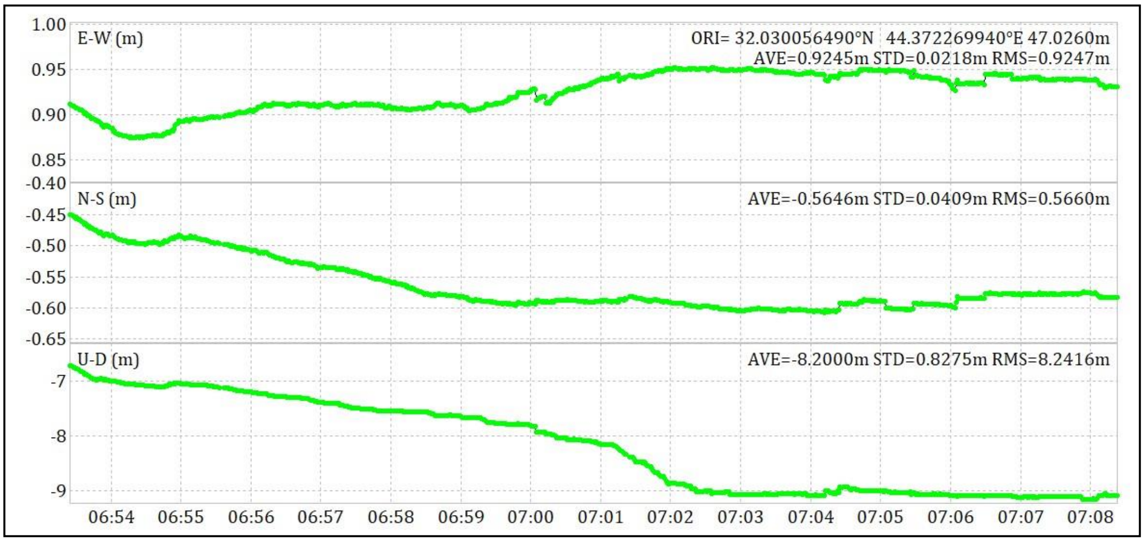

Fig. 6 Accuracy of GNSS data collected by G-RitZ with PPP technique and all constellations.

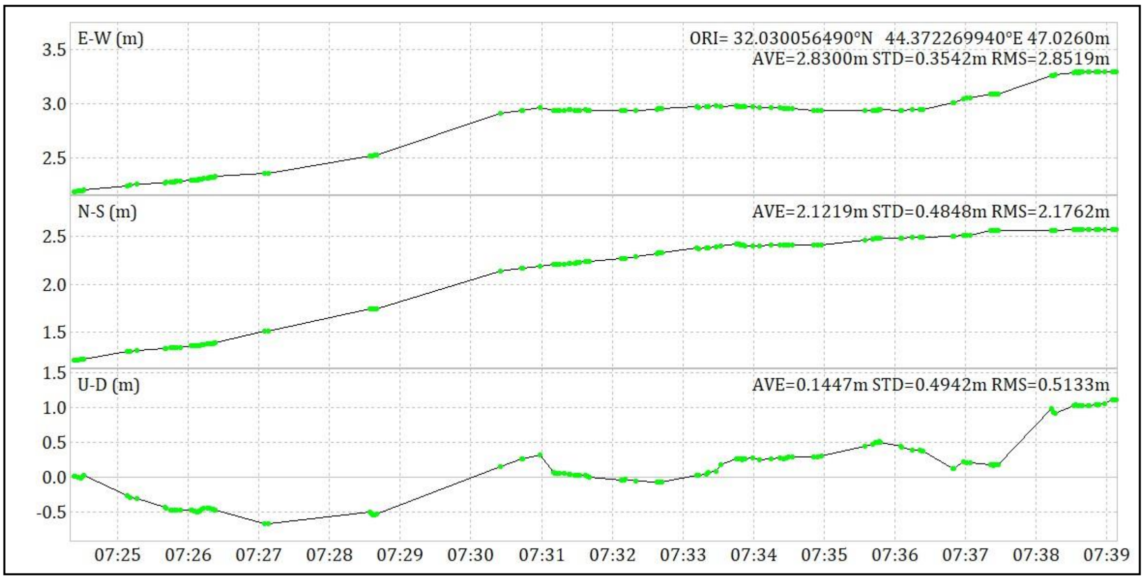

Fig. 7 Accuracy of GNSS data collected by rinex ON with PPP technique and all constellations.

The next processing was based on PPS technique for all constellations. Table 3 revels the list of all results of this processing. In addition, figures (**Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.**) show the accuracies of output solutions at different epochs for different Apps. Based on standard deviation, the precisions at this time are consistent for all Apps in horizontal position and vary a little in vertical position. However, the positional accuracy calculated from Rinex ON data is still inconsistent with other Apps.

Also, the positional accuracy obtained from GnssLogger data is better than expected and reaches as accurate as a few centimeters. This is possible because the noise of data is minimal with no multipath. In addition, nearly all biases were eliminated through differencing considering base station observation. Furthermore, five minutes is also enough to give the same solution accuracy for an open sky where many satellites are available and hence good DOP with minimum multipath.

Table 3. Test results of different Apps with PPS technique and different constellations.

App	GNSS	No obs.	E-W (m)			N-S (m)			U-D (m)		
			Avg.	STD	RMS	Avg.	STD	RMS	Avg.	STD	RMS
GnssLogger	GPS	829	0.021	0.026	0.034	0.162	0.052	0.171	0.355	0.144	0.383
	GLO	681	3.215	0.007	3.216	3.282	0.009	3.282	10.689	0.119	10.690
	GAL	819	0.422	0.111	0.437	0.890	0.144	0.901	0.690	0.659	0.953
	Multi	829	0.182	0.021	0.184	0.076	0.018	0.078	0.596	0.076	0.601
G-RitZ	GPS	901	1.014	0.016	1.014	0.038	0.038	0.054	6.666	0.010	6.666
	GLO	895	0.624	0.314	0.699	3.029	0.213	3.036	29.760	2.630	29.876
	GAL	889	1.005	0.134	1.013	3.654	0.227	3.661	2.811	0.293	2.827
	Multi	901	0.909	0.030	0.910	1.839	0.017	1.839	6.509	0.136	6.510
rinex ON	GPS	901	0.609	0.041	0.611	1.613	0.042	1.614	3.045	0.072	3.046
	GLO	849	13.343	0.449	13.350	9.775	0.377	9.782	129.001	1.311	129.008
	GAL	868	1.049	0.302	1.092	1.632	0.253	1.652	2.146	1.228	2.472
	Multi	901	2.434	0.084	2.435	0.084	0.046	0.096	4.712	0.178	4.716

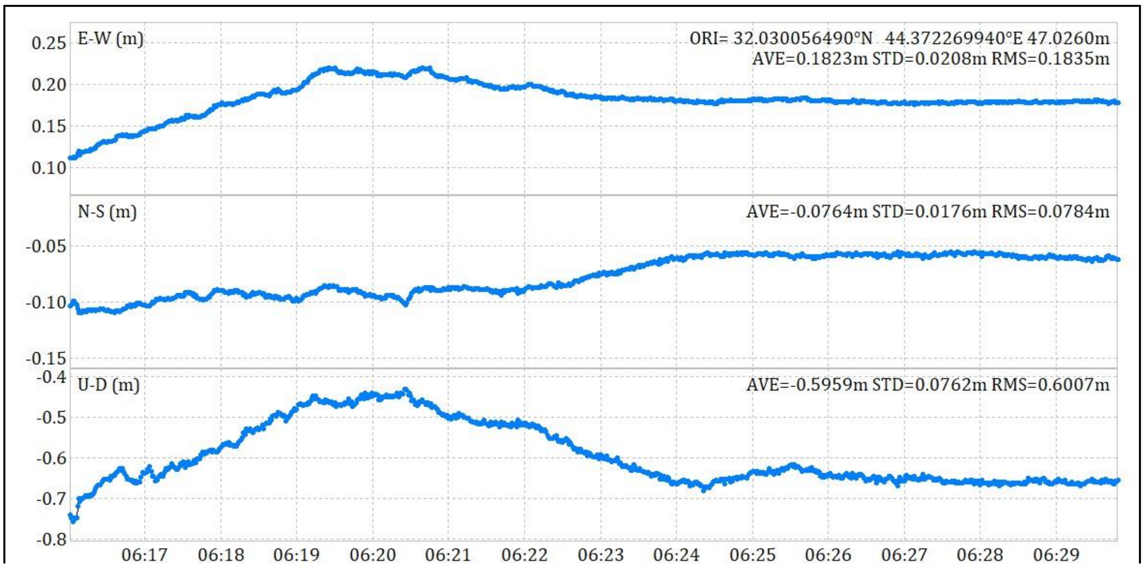

Fig. 8 Accuracy of GNSS data collected by GnssLogger with PPS technique and all constellations.

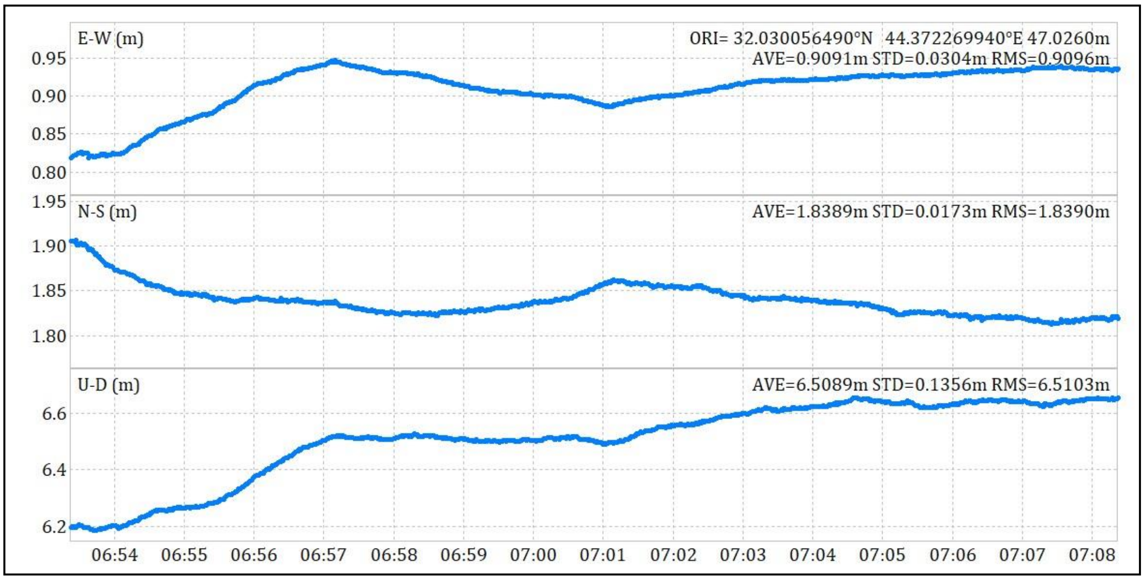

Fig. 9 Accuracy of GNSS data collected by G-RitZ with PPS technique and all constellations.

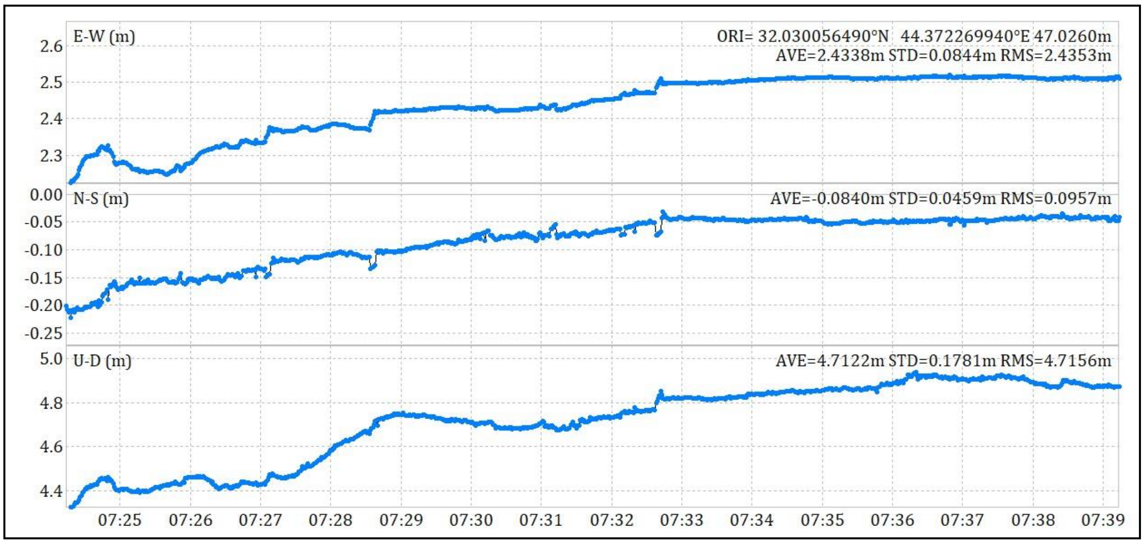

Fig. 10 Accuracy of GNSS data collected by rinex ON with PPS technique and all constellations.

In order to assess accuracies with regard to different constellations, additional processing has been conducted. Firstly, utilising PPP technique, the Apps data has been processed separately for each constellation (GPS, GLONASS, and GALILEO) (Table 2, **Error! Reference source not found.** to **Error! Reference source not found.**). Obviously, the number of observations employed in the processing is few in GLONASS and GALILEO compared to that of GPS in GnssLogger, and gives no solution at all for other Apps. This is possibly for two reasons: firstly, the data noise is high for these constellations, more than the threshold, and consequently was omitted in processing. The second reason is probably due to the device's priority as it is tracking GPS satellites and dealing with other constellations as augmentations (Håkansson, 2018b). For GnssLogger, the multi-constellation results are better than those of a single system. Whereas, they are nearly the same or better in only GPS single solution for G-RitZ and rinexON respectively.

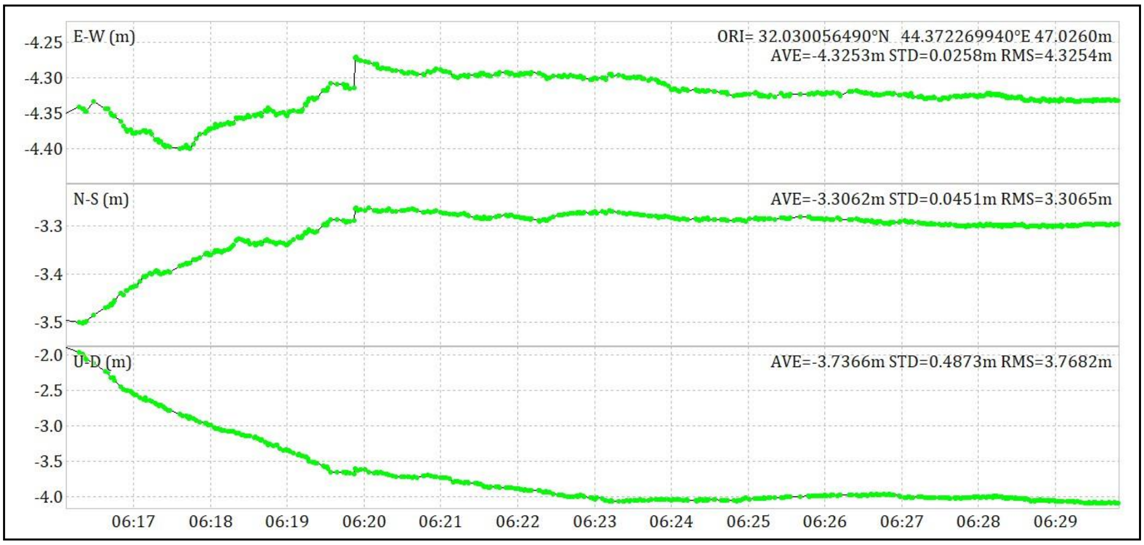

Fig. 11 Test results of GnssLogger with PPP technique and GPS constellation.

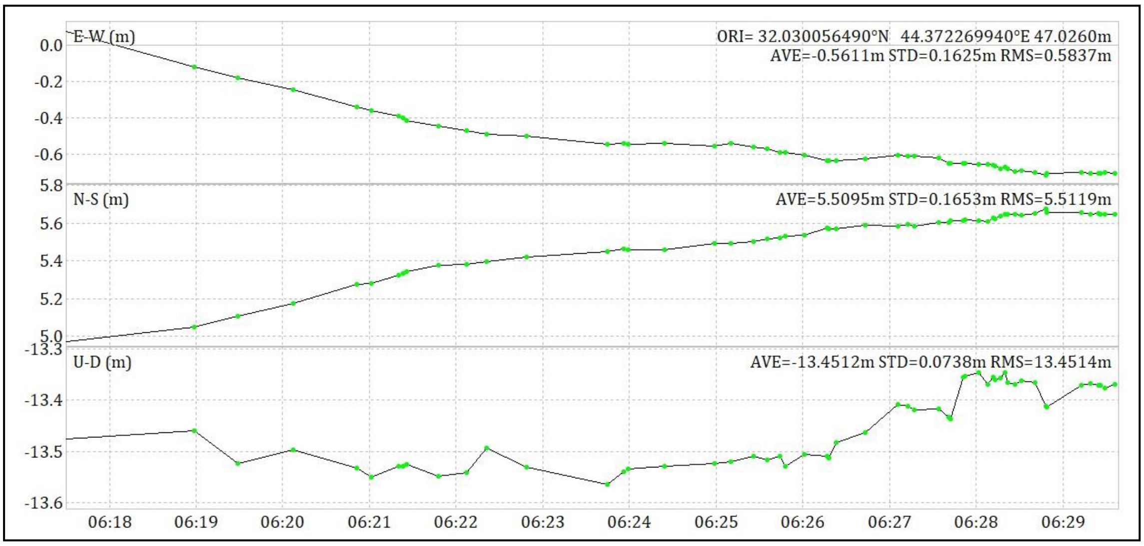

Fig. 12 Test results of GnssLogger with PPP technique and GLONASS constellation.

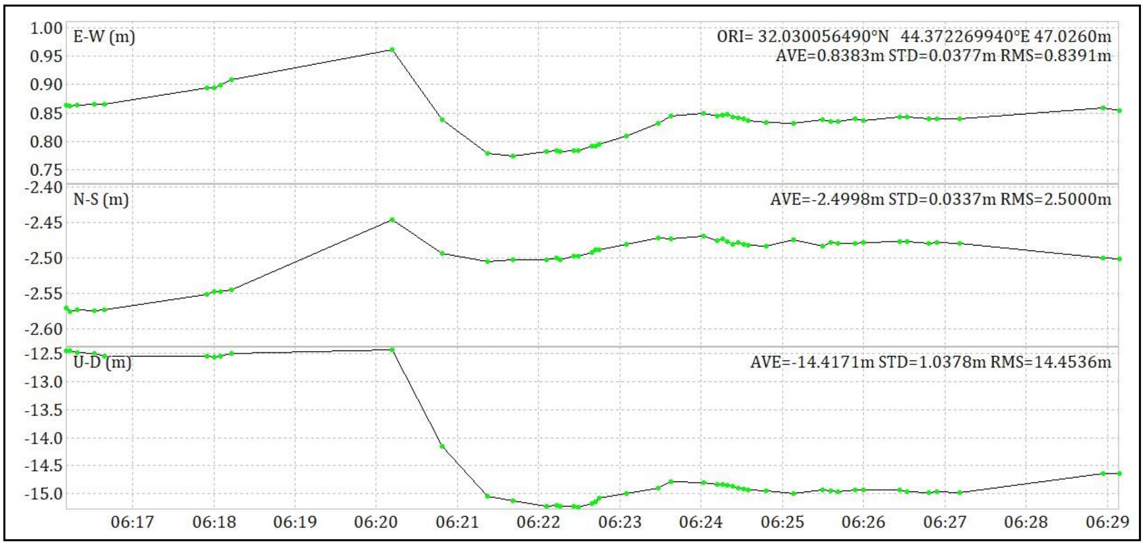

Fig. 13 Test results of GnssLogger with PPP technique and GALILEO constellation.

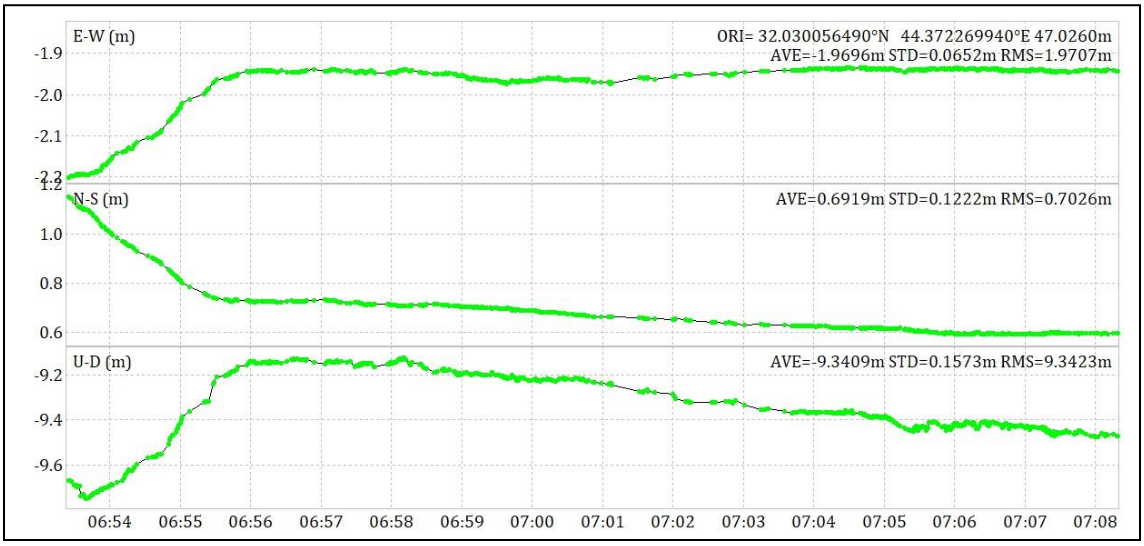

Fig. 14 Test results of G-RitZ with PPP technique and GPS constellation

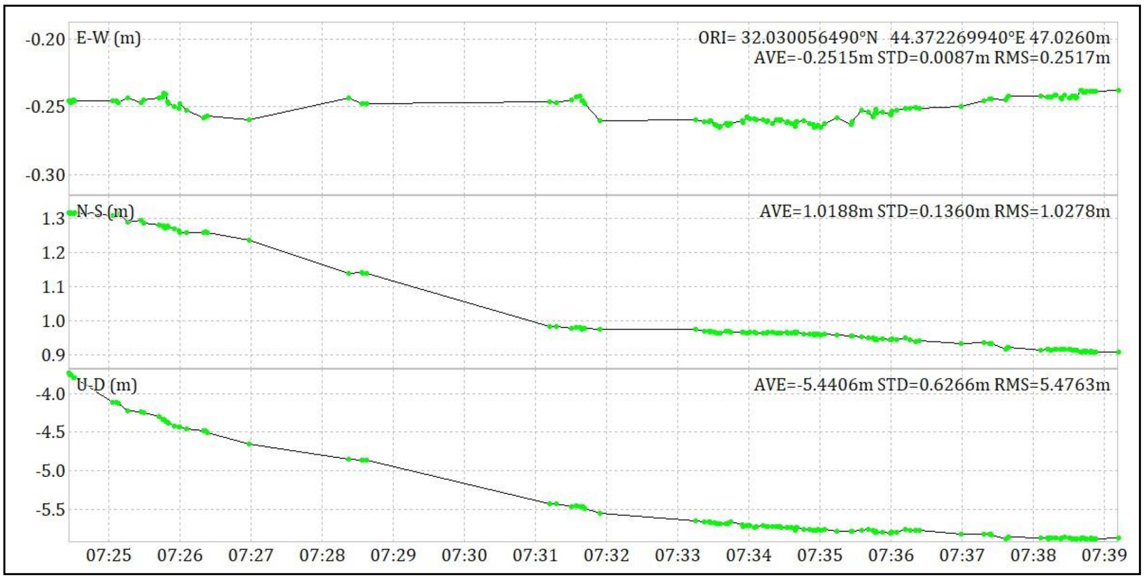

Fig. 15 Test results of rinex ON with PPP technique and GPS constellation.

Finally, PPS was applied to data in a single constellation system solution (Table 3, Fig. 1 to Fig. 9). Unlike PPP, due to no restrictions for data employed, the processing gave a solution for all constellations for all Apps. Expectedly, the best results were obtained from GPS constellation and GnssLogger. In addition, the results reveal a gross error in solutions for GLONASS constellation, especially for G-RitZ and rinex ON Apps. This will discuss more in the next section.

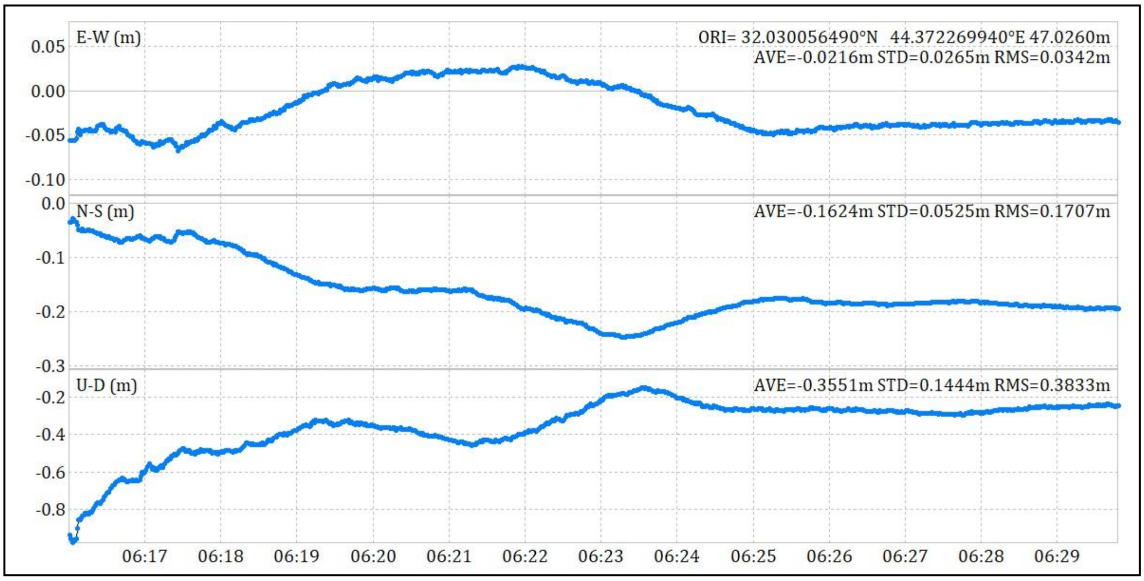

Fig. 1 Test results of GnssLogger with PPS technique and GPS constellation.

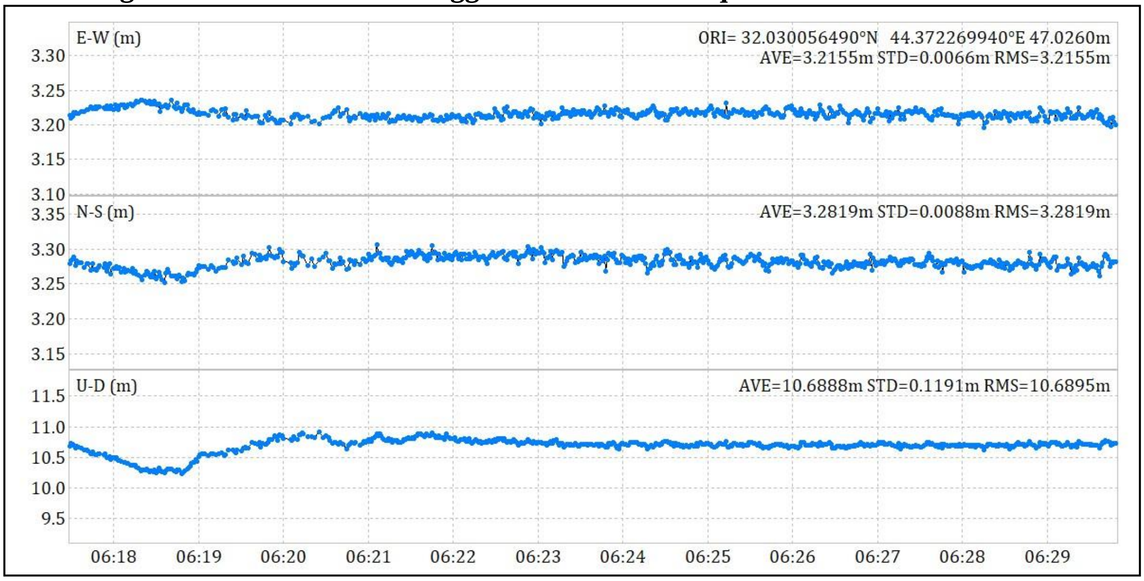

Fig. 2 Test results of GnssLogger with PPS technique and GLONASS constellation.

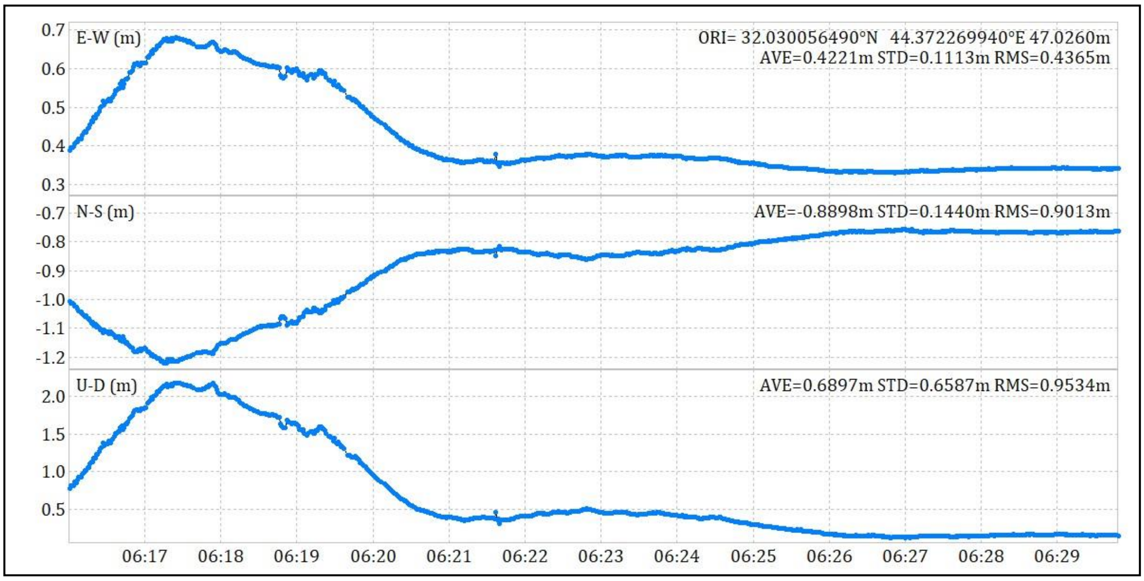

Fig. 3 Test results of GnssLogger with PPS technique and GALILEO constellation.

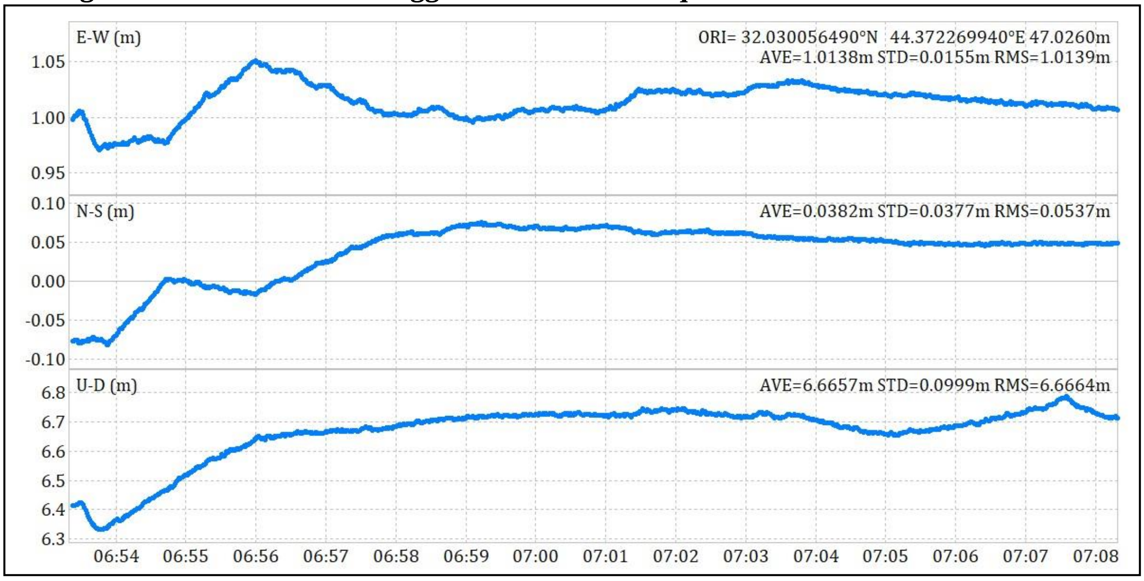

Fig. 4 Test results of G-RitZ with PPS technique and GPS constellation.

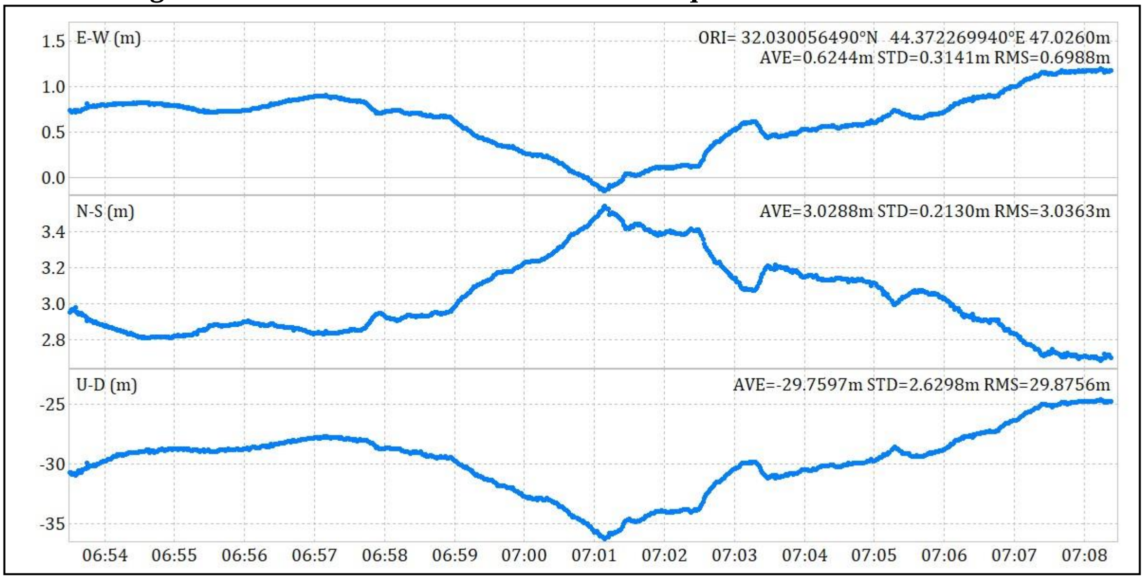

Fig. 5 Test results of G-RitZ with PPS technique and GLONASS constellation.

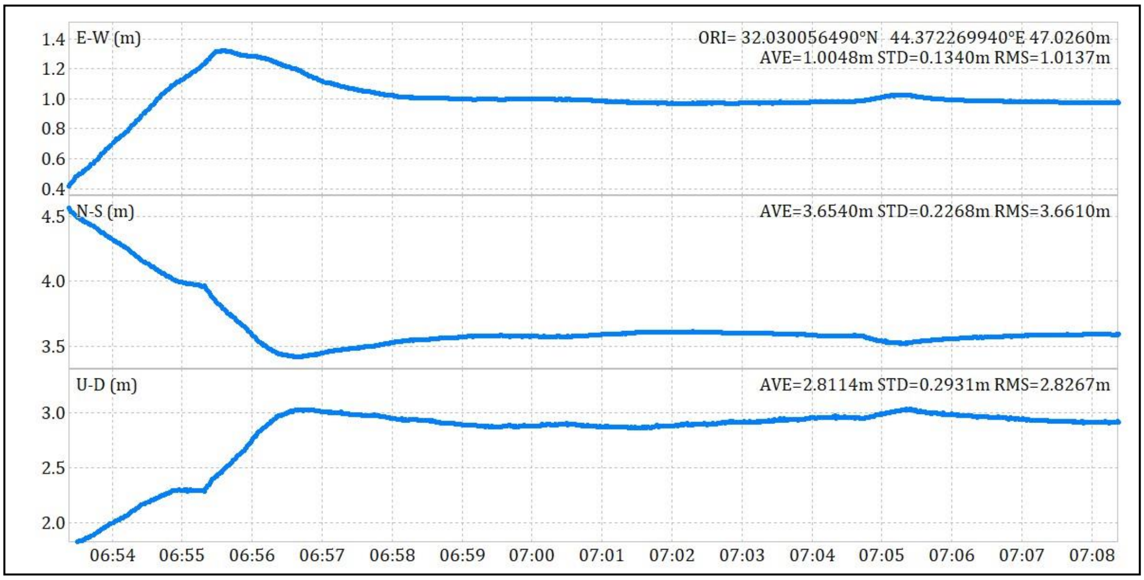

Fig. 6 Test results of G-RitZ with PPS technique and GALILEO constellation.

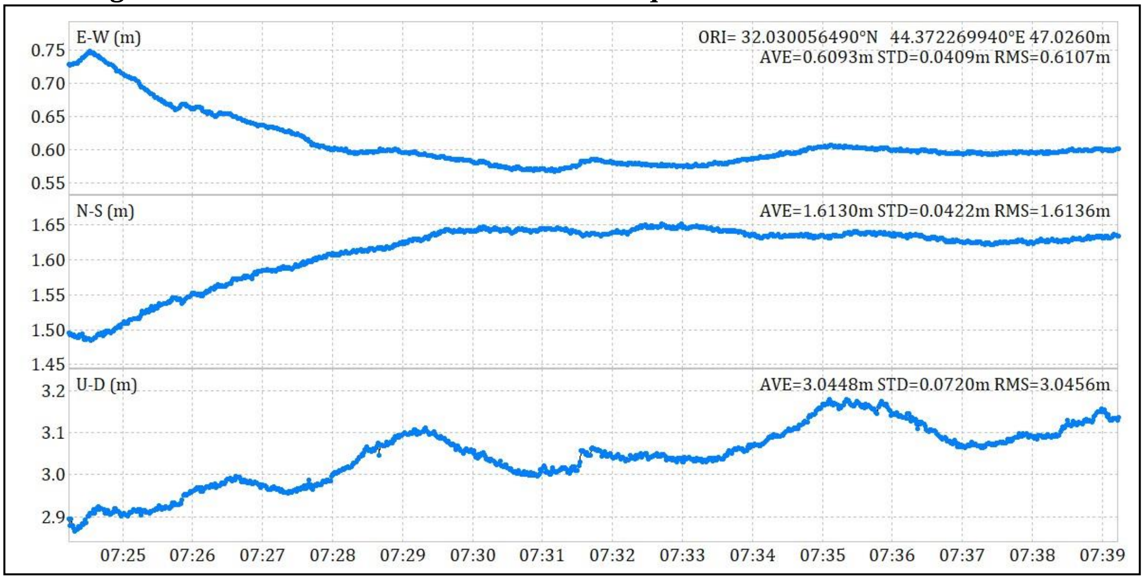

Fig. 7 Test results of rinex ON with PPS technique and GPS constellation.

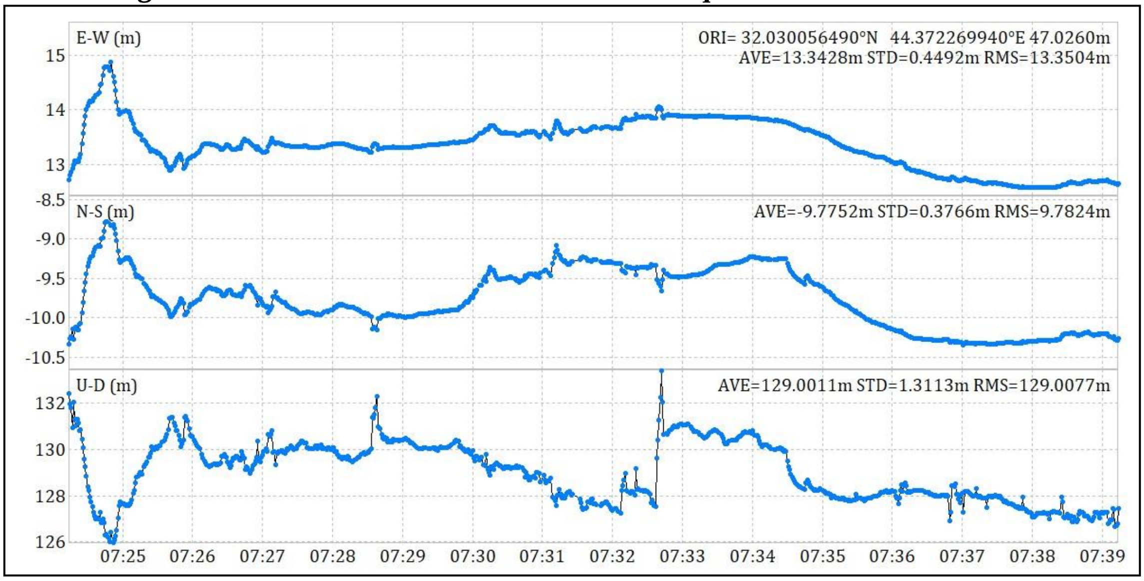

Fig. 8 Test results of rinex ON with PPS technique and GLONSS constellation.

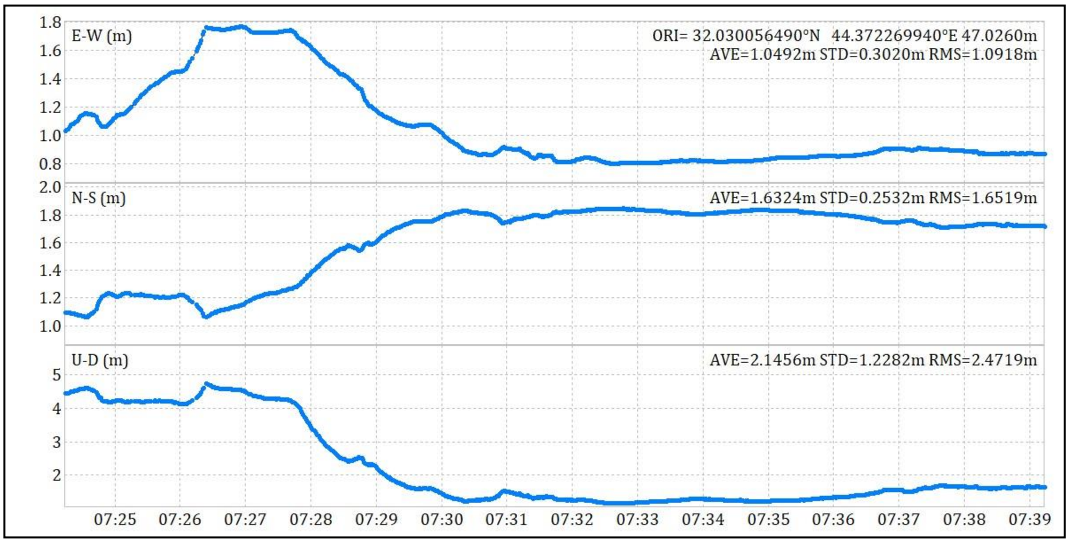

Fig. 9 Test results of rinex ON with PPS technique and GALILEO constellation.

5. ANALYSIS AND DISCUSSION

The analysis is based on the idea that the PPP solution is the best method for comparison purposes between different Apps data because it is sensitive to noise. Previous studies by (Borio et al. ,2016) and (Grenier et al.,2023) have demonstrated the effectiveness of PPP in assessing GNSS data accuracy. On the other hand, the PPS technique is employed to assess the accuracy of solutions by different constellations since almost all biases are eliminated in processing by differencing, remaining noise, and multipath. This approach aligns with findings from (Zangenehnejad and Gao, 2021), who highlighted the advantages of PPS in mitigating biases and enhancing accuracy in GNSS positioning. For both cases, the RMSs are utilised. Hence, from the summarized PPP results shown in figures (Fig. 23, Fig. 24, and Fig. 25) the GnssLogger data has less noise and consequently gave a logical solution for different GNSS constellations. This finding is consistent with the observations made by (Liu et al., 2023), who also found reduced noise levels in GNSS data collected by smartphones. Whereas, G-Ritz and Rinex ON data are considered to be contaminated with noise due to the fact that there is no solution for these Apps when employing GLONASS and GALILEO. Previous research by (Lachapelle and Gratton, 2019) and (Li et al. ,2022) has also reported challenges with GLONASS and GALILEO data processing in smartphone-based GNSS applications. On the other hand, PPS technique results reveal consistency for GPS constellation for all Apps (Fig. 26, Fig. 27, and Fig. 28). This finding corroborates with the results of (Chen et al. ,2019), who also observed consistent accuracy with GPS-based positioning techniques in smartphone GNSS data processing. Whereas, GLONASS results showed the worst accuracy for all Apps. This is probably because of ISB (mentioned early) and inter-frequency biases (IFBs) come from using Frequency Division Multiple Access (FDMA) in the GLONASS system which results from the receiver hardware as an impact on the signal processing of the different carrier frequencies (Håkansson, 2018b).

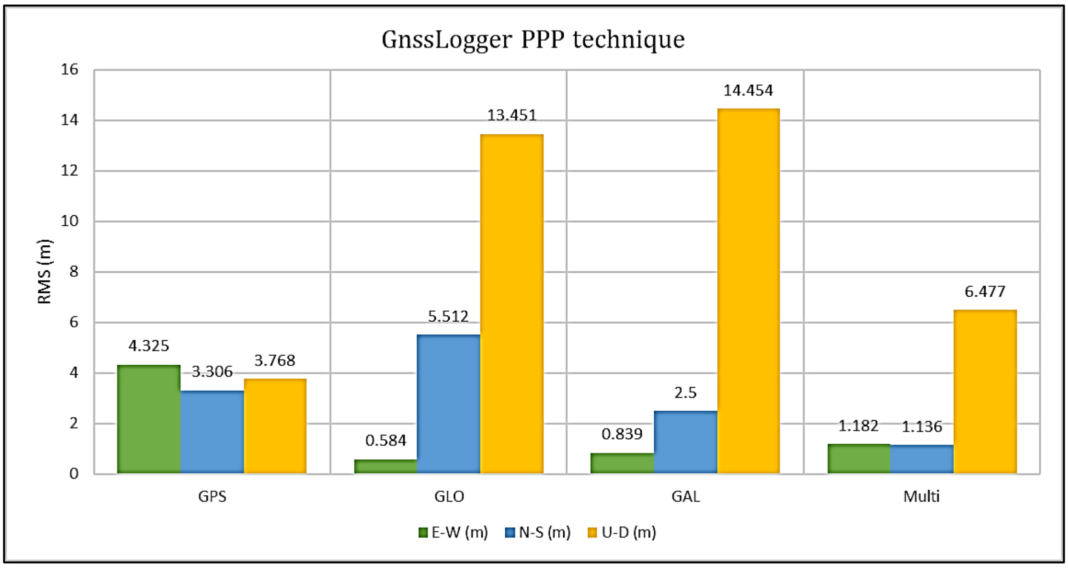

Fig. 10 Summarized PPP results for GnssLogger App for different constellations.

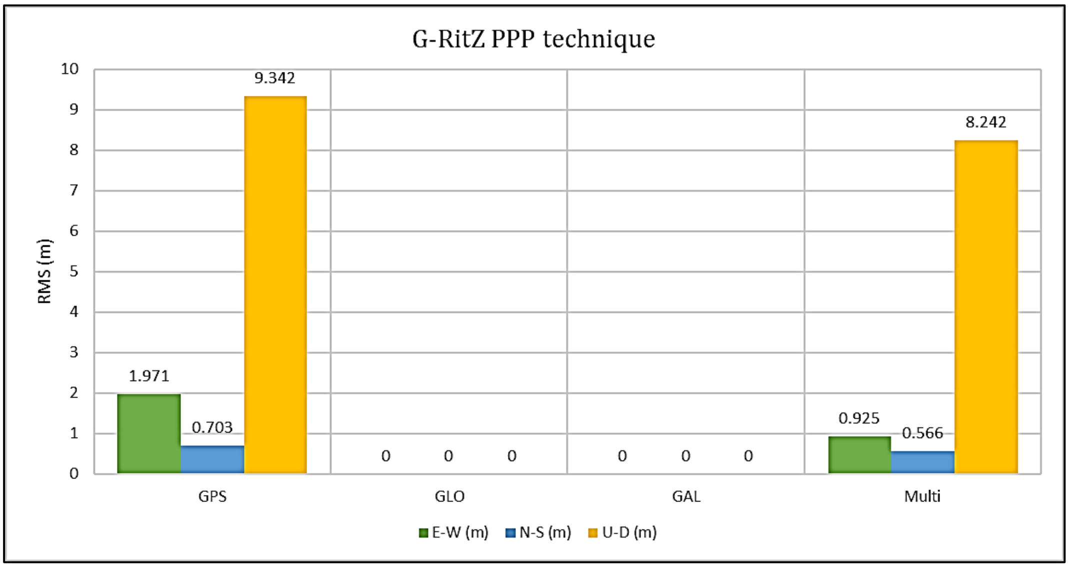

Fig. 11 Summarized PPP results for G-RitZ App for different constellations.

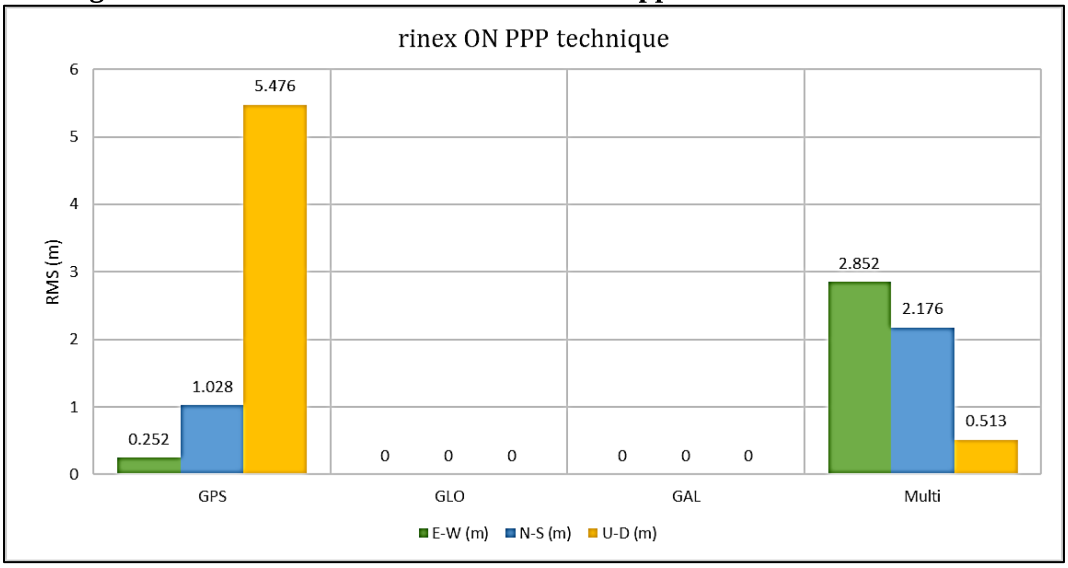

Fig. 12 Summarized PPP results for rinex ON App for different constellations.

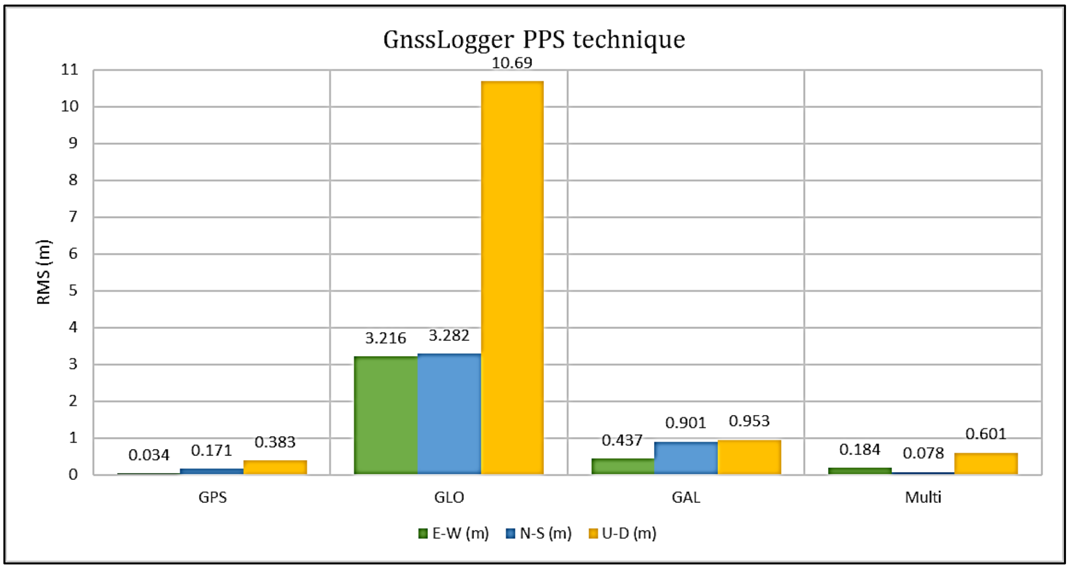

Fig. 13 Summarized PPS results for GnssLogger App for different constellations.

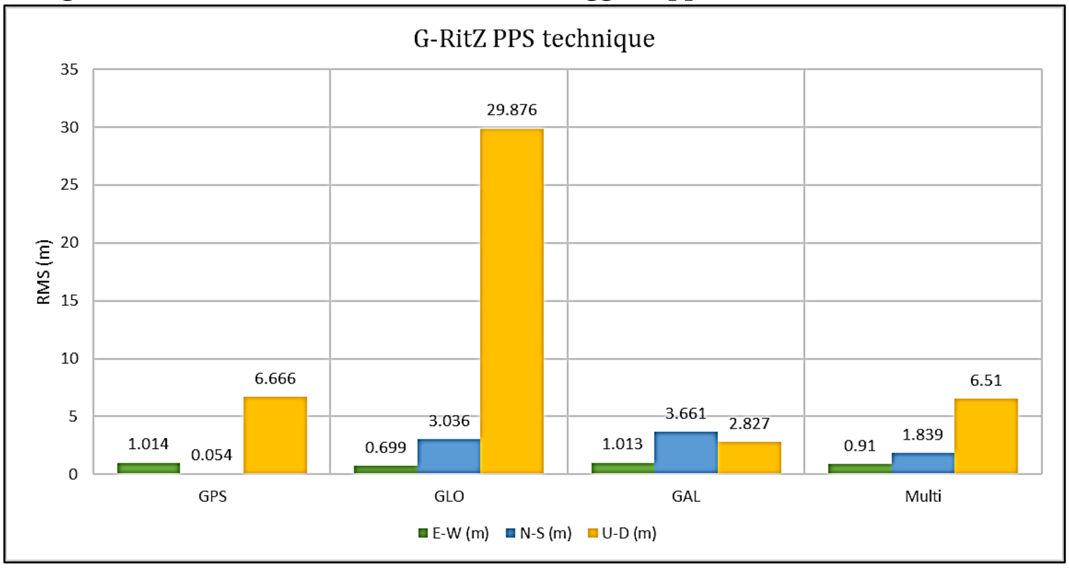

Fig. 14 Summarized PPS results for G-RitZ App for different constellations

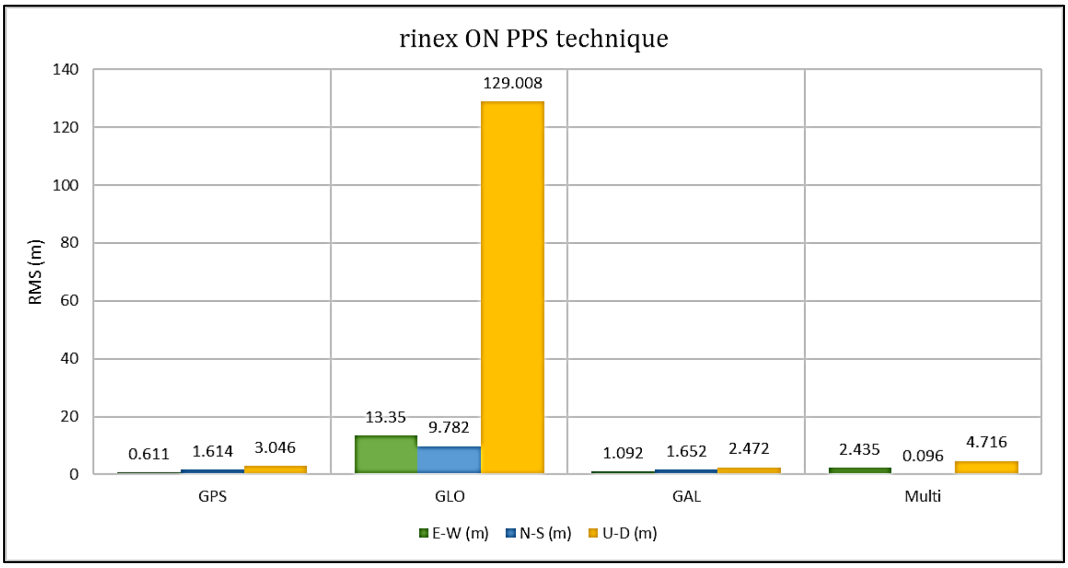

Fig. 15 Summarized PPS results for rinex ON App for different constellations

To substantiate our conclusion that GnssLogger is the optimal choice for collecting GNSS data via smartphones, we incorporate findings from prior studies in our discussion. (Borio and Borio et al. , 2016), (Grenier et al. ,2023),(Liu et al. , 2023),(Lachapelle and Gratton , 2019), (Li et al. ,2022), (Zhu et al. ,2020) and (Håkansson ,2018a) have extensively explored GNSS data collection and processing using smartphone applications. Their research supports our observation that GnssLogger consistently offers superior data quality and accuracy compared to other applications. By aligning our findings with these studies, we reinforce the robustness of our conclusion regarding the effectiveness of GnssLogger for smartphone-based GNSS data collection.

6. CONCLUSIONS

In this study, we aimed to assess the accuracy of GNSS data collected by different smartphone applications (Apps) and evaluate the performance of various constellations using precise point positioning (PPP) and post-processing static (PPS) techniques. The research gap addressed was the need to understand the quality and accuracy of GNSS data collected by smartphones and the impact of different constellations on positioning accuracy.

Our methodology involved employing PPP to evaluate data quality and PPS for comparing accuracy across different constellations. The results indicate that PPP is sensitive to noise, with GnssLogger and G-RitZ exhibiting better data quality compared to Rinex ON. Additionally, PPS analysis revealed GPS to be the most accurate constellation, outperforming GLONASS and GALILEO, likely due to its availability and tracking priority in smartphone software.

The research limitations include the susceptibility of smartphone GNSS data to noise and multipath errors, which may affect solution accuracy, particularly after the initial convergence period. Furthermore, the study's findings may be influenced by factors such as receiver hardware and environmental conditions.

In summary, our research provides insights into assessing GNSS Apps data quality, determining convergence time for accurate solutions, and identifying optimal constellation scenarios for smartphone GNSS processing. The study underscores the importance of validating observed data and highlights the potential for achieving high accuracy with smartphone GNSS, particularly in GPS and multi-constellation scenarios. However, further research is needed to address the limitations and explore advanced techniques for enhancing smartphone GNSS positioning accuracy.

As a results, GnssLogger is considered as the best for collecting GNSS data by smartphones.

For future prospects and next work, it is supposed to synchronise smartphone camera with GNSS data to get accurate georeferenced photos.

Acknowledgment

This research received no external funding but it is part of the research activities made at the University of Kufa/Remote Sensing Centre, thanks to facilities of this centre such as software and computers where they were used in this research.

7. REFERENCES

AGGREY, J., BISNATH, S., NACIRI, N., SHINGHAL, G. & YANG, S. 2020. Multi-GNSS precise point positioning with next-generation smartphone measurements. Journal of Spatial Science, 65, 79-98.

BANVILLE, S. & VAN DIGGELEN, F. 2016. Precise positioning using raw GPS measurements from Android smartphones. GPS world, 27, 43-48.

BORIO, D., DOVIS, F., KUUSNIEMI, H. & LO PRESTI, L. 2016. Impact and Detection of GNSS Jammers on Consumer Grade Satellite Navigation Receivers. Proceedings of the IEEE, 104, 1233-1245.

CHEN, B., GAO, C., LIU, Y. & SUN, P. 2019. Real-time Precise Point Positioning with a Xiaomi MI 8 Android Smartphone. Sensors, 19, 2835.

DABOVE, P. & DI PIETRA, V. 2019a. Single-baseline RTK positioning using dual-frequency GNSS receivers inside smartphones. Sensors, 19, 4302.

DABOVE, P. & DI PIETRA, V. 2019b. Towards high accuracy GNSS real-time positioning with smartphones. Advances in Space Research, 63, 94-102.

DABOVE, P., DI PIETRA, V. & PIRAS, M. 2020. GNSS Positioning Using Mobile Devices with the Android Operating System. ISPRS International Journal of Geo-Information, 9, 220.

ELMEZAYEN, A. & EL-RABBANY, A. 2019. Precise Point Positioning Using World's First Dual-Frequency GPS/GALILEO Smartphone. Sensors, 19, 2593.

FORTUNATO, M., CRITCHLEY-MARROWS, J., SIUTKOWSKA, M., IVANOVICI, M. L., BENEDETTI, E. & ROBERTS, W. 2019. Enabling High Accuracy Dynamic Applications in Urban Environments Using PPP and RTK on Android Multi-Frequency and Multi-GNSS Smartphones. 2019 European Navigation Conference (ENC), 1-9.

GOGOI, N., MINETTO, A., LINTY, N. & DOVIS, F. 2019. A Controlled-Environment Quality Assessment of Android GNSS Raw Measurements. Electronics, 8.

GRENIER, A., LOHAN, E. S., OMETOV, A. & NURMI, J. 2023. Towards Smarter Positioning through Analyzing Raw GNSS and Multi-Sensor Data from Android Devices: A Dataset and an Open-Source Application. Electronics, 12, 4781.

HÅKANSSON, M. 2018a. Analysis of carrier phase and code observations from multi-GNSS constellations in urban environments Master Thesis.

HÅKANSSON, M. 2018b. Characterization of GNSS observations from a Nexus 9 Android tablet. GPS Solutions, 23, 21.

HU, J., YI, D. & BISNATH, S. 2023. A Comprehensive Analysis of Smartphone GNSS Range Errors in Realistic Environments. Sensors (Basel), 23.

KARKI, B. & WON, M. 2020b. Characterizing Power Consumption of Dual-Frequency GNSS of Smartphone. GLOBECOM 2020 - 2020 IEEE Global Communications Conference. Taipei, Taiwan.

KARKI, B. & WON, M. Characterizing Power Consumption of Dual-Frequency GNSS of Smartphone. GLOBECOM 2020-2020 IEEE Global Communications Conference, 2020a. IEEE, 1-6.

LACHAPELLE, G. & GRATTON, P. 2019. GNSS Precise Point Positioning with Android Smartphones and Comparison with High Performance Receivers. 2019 IEEE International Conference on Signal, Information and Data Processing (ICSIDP). Chongqing, China.

LI, G. & GENG, J. 2019. Characteristics of raw multi-GNSS measurement error from Google Android smart devices. GPS Solutions, 23, 90.

LI, Z., WANG, L., WANG, N., LI, R. & LIU, A. 2022. Real-time GNSS precise point positioning with smartphones for vehicle navigation. Satellite Navigation, 3.

LIU, Q., GAO, C., SHANG, R., GAO, W. & ZHANG, R. 2023. Multifrequency Signal Characterization and Assessment of GNSS Positioning in Smartphone. IEEE Transactions on Instrumentation and Measurement, 72, 1-9.

LIU, Y., GAO, C., CHEN, B. & ZHANG, R. Pseudo-Range Single Point and Differential Positioning Accuracy Test Based on Android Smartphone. China Satellite Navigation Conference, 2019 Beijing, China. Springer Nature Singapore Pte Ltd, 72–81.

MASSARWEH, L., FORTUNATO, M. & GIOIA, C. 2020. Assessment of Real-time Multipath Detection with Android Raw GNSS Measurements by Using a Xiaomi Mi 8 Smartphone. 2020 IEEE/ION Position, Location and Navigation Symposium (PLANS). Portland, OR, USA.

MOHANTY, A. & GAO, G. 2023. Learning GNSS Positioning Corrections for Smartphones Using Graph Convolution Neural Networks. NAVIGATION: Journal of the Institute of Navigation, 70, navi.622.

NIU, Z., NIE, P., TAO, L., SUN, J. & ZHU, B. 2019a. RTK with the Assistance of an IMU-Based Pedestrian Navigation Algorithm for Smartphones. Sensors, 19, 3228.

NIU, Z., NIE, P., TAO, L., SUN, J. & ZHU, B. 2019b. RTK with the Assistance of an IMU-Based Pedestrian Navigation Algorithm for Smartphones. Sensors (Basel), 19.

ROBUSTELLI, U., BAIOCCHI, V. & PUGLIANO, G. 2019. Assessment of Dual Frequency GNSS Observations from a Xiaomi Mi 8 Android Smartphone and Positioning Performance Analysis. Electronics, 8, 91.

SHINGHAL, G. & BISNATH, S. 2021. Conditioning and PPP processing of smartphone GNSS measurements in realistic environments. Satellite Navigation, 2, 10.

SPECHT, C., DABROWSKI, P. S., PAWELSKI, J., SPECHT, M. & SZOT, T. 2019. Comparative analysis of positioning accuracy of GNSS receivers of Samsung Galaxy smartphones in marine dynamic measurements. Advances in Space Research, 63, 3018-3028.

SUBEDI, S. & PYUN, J. Y. 2020. A Survey of Smartphone-Based Indoor Positioning System Using RF-Based Wireless Technologies. Sensors (Basel), 20.

SZOT, T., SPECHT, C., SPECHT, M. & DABROWSKI, P. S. 2019. Comparative analysis of positioning accuracy of Samsung Galaxy smartphones in stationary measurements. PloS one, 14, e0215562-e0215562.

TAKASU, T. 2013. RTKLIB Manual. Tokyo/ Japan: the Tokyo University of Marine Science and Technology

THE GSA GNSS RAW MEASUREMENTS TASK FORCE, E. 2017. Using GNSS Raw Measurements on Android Devices. In: GSA (ed.). the Czech Republic European GNSS Agency.

WANG, J., WENG, D., QU, X., DING, W. & CHEN, W. 2023. A Novel Deep Odometry Network for Vehicle Positioning Based on Smartphone. IEEE Transactions on Instrumentation and Measurement, 72, 1-12.

WU, Q., SUN, M., ZHOU, C. & ZHANG, P. 2019. Precise point positioning using dual-frequency GNSS observations on smartphone. Sensors, 19, 2189.

ZANGENEHNEJAD, F. & GAO, Y. 2021. GNSS smartphones positioning: advances, challenges, opportunities, and future perspectives. Satell Navig, 2, 24.

ZHU, H., XIA, L., WU, D., XIA, J. & LI, Q. 2020. Study on Multi-GNSS Precise Point Positioning Performance with Adverse Effects of Satellite Signals on Android Smartphone. Sensors (Basel), 20.