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RESEARCH ARTICLE

Exploring Absolute GNSS for Positioning without Internet Connectivity: Evaluating SPP and PPP Performance for High-Accuracy Applications

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Abstract
This study investigates the accuracy of offline Global Navigation Satellite System (GNSS) in remote areas where there are no internet connectivity. The research focused on offline Single Point Positioning (SPP) and Precise Point Positioning (PPP) techniques, comparing their accuracy and assessing the impact of observation duration on offline SPP accuracy. The instruments used include Hi-Target v30 GNSS receiver and its accessories, Hi-Target Geomatics office software. The offline SPP data were obtained using the Hi-Target Geomatics office software. The PPP data were obtained using the offline SPP data that were converted to RINEX file and uploaded to CSRS-PPP online platform. Observations were carried out in 1 hour and 2 hours on different points respectively. The comparisons were done and the various charts were plotted as well to analyze the process. The results showed that offline SPP achieves higher accuracy with error ranges of 0.36m to 1.18m when observations last for 2-hour and between 1.67m to 3.48m for when observations last for 1-hour. The study demonstrates that longer observation periods improve offline GNSS SPP accuracy thereby reducing noise and multipath effects. The findings have significant implications for surveying and mapping applications in remote areas, where accurate positioning is crucial but without internet services.

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1.0 INTRODUCTION

1.1 Background to the Study

Absolute GNSS positioning uses an autonomous receiver to exclusively receive signals transmitted by Global Navigation Satellite Systems' (GNSS) satellites to determine its precise location without reliance on reference data from a separate station (Trimble, 2024; Chen et al. 2023; Zhu et al, 2024 and Reid et al. 2019). Bisnath and Gao (2009) affirmed that the absolute GNSS Positioning is useful in mapping and uses autonomous GNSS receiver to produce navigation and positioning data in offline SPP or PPP mode. In recent times too, a positioning infrastructure known as Continuously Operating Reference stations (CORS) have encouraged the use of single receiver to fix positions and this CORS is deeply intertwined with internet connectivity like the PPP (Oladosu et al, 2022). Birinci and Saka (2021) established that, the distinction between offline SPP and PPP being techniques use in absolute GNSS positioning lie in their fundamental methodologies and resulting accuracies. It is an established fact that the offline SPP uses the pseudorange measurements from a single GNSS receiver to estimate the distance from the receiver to each satellite, and then uses trilateration to determine receiver's position on any point on the earth's surface. SPP is suitable for applications requiring moderate accuracy like within 5 – 10m (Deo and El-Mowafy, 2020;

Shevchuk et al., 2020; Zhao et al, 2021). The ephemeris data include the precise satellite orbit and clock corrections, as well as other atmospheric delay corrections (Birinci and Saka, 2021). PPP is ideal for scenarios demanding high precision, such as surveying, mapping, and precise navigation (Zumberge, 1997; Kouba and Heroux, 2001).

In the realm of surveying and mapping, Absolute GNSS Positioning when used in PPP mode provides accurate positioning, enabling experts to create detailed topographical maps and conduct thorough land surveys (Al Shouny et al, 2024). The aviation and aerospace industries also benefit from Absolute GNSS Positioning, which is used in aircraft navigation systems, precision approach, and landing systems. El-Mowafy (2011) elaborated absolute GNSS Positioning plays a vital role in maritime navigation, providing accurate positioning for ships, boats, and other vessels. Radocaj et al, (2023) explained also that, precision agriculture relies on Absolute GNSS Positioning to enable autonomous farming equipment, crop monitoring, and yield optimization.

Scientific research also leverages Absolute GNSS Positioning's capabilities, with applications in geophysics, seismology, and meteorology (Guma *et al*, 2023). Akpinar and Aykut (2017) stressed that, mining and exploration operations benefit from Absolute GNSS Positioning's precise positioning, which aids in geological mapping and mineral exploration. Emergency responders search and rescue teams, and disaster relief efforts also rely on Absolute GNSS Positioning for accurate positioning. Furthermore, Absolute GNSS Positioning plays a crucial role in the development of autonomous vehicles, enabling precise positioning and navigation. The technology also provides accurate timing and synchronization for various applications, including telecommunications, finance, and scientific research (Xu et al, 2011).
In addition, Du *et al* (2021) explained that the Absolute GNSS Positioning is used in geological monitoring, enabling precise tracking of geological movements, such as landslides, earthquakes, and volcanic activity. Guma *et al* (2021) discussed that Environmental monitoring also benefits from Absolute GNSS Positioning, which provides accurate positioning for monitoring displacement and velocities of terrains prone to incessant quarrying of limestone and other minerals.

The motivation behind this study stems from the challenges faced by surveyors in remote or underserved areas where essential infrastructure, such as CORS, secondary or tertiary order control points and internet connectivity, is nonexistent. In these environments, conducting survey operations can be extremely difficult, if not impossible. Hence, this study aims to explore the absolute Global Navigation Satellite System (GNSS) for positioning without internet services. The primary objectives of this research include: conducting a comparative error analysis to determine the range of errors in Single Point Positioning (SPP) solutions relative to Precise Point Positioning (PPP) solutions, and carrying out an observation Period Accuracy Assessment to investigate the relationship between observation period duration and accuracy in SPP solutions.

2.0 REVIEW OF RELATED LITERATURE

2.1 Conducting a Comparative Error Analysis

Abdelazeem and Çelik (2014) in a comprehensive analysis conducted a study to assess the performance of the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service. To facilitate this investigation, dual-seasonal observations were collected in January and July. These observations were subsequently processed using the CSRS-PPP online service. The resulting coordinates were rigorously compared to the true coordinates of the stations, which served as a reference framework. This comparative analysis revealed that the CSRS-PPP service achieves remarkable accuracy, with horizontal and height components exhibiting errors of ±(1 to 4) mm and ±(2 to 7) mm, respectively. Furthermore, an assessment of the repeatability of the CSRS-PPP solutions yielded encouraging results, with values ranging from ±(1 to 5) mm in both horizontal directions. These findings underscore the reliability and consistency of the CSRS-PPP service, reinforcing its suitability for applications requiring high-precision positioning.
Malinowski and Kwiecień (2016) explained that, PPP is very useful in areas with limited ground station infrastructure. In their study, they presented a comparative analysis of the accuracy of absolute position determination using observations ranging from 1 to 7 hours. The analysis utilized four permanent services that employ the PPP technique: Automatic Precise Positioning Service (APPS), Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP), GNSS Analysis and Positioning Software (GAPS), and magicPPP Solution (magicGNSS). The results obtained without clock product application indicated that measurements lasting at least two hours could achieve an absolute position accuracy of 2 - 4 cm. When the clock products and the correction errors were modeled, the results showed that two-hour

measurement sessions was able to achieve horizontal distances alongside height differences with accuracy of 1-2 cm.
Pepe et al, (2021) focused on evaluating the positioning accuracy of smartphones using pseudorange measurements in Differential Global Navigation Satellite System (DGNSS) and Single Point Positioning (SPP). The experimental results revealed that SPP could achieve a comparable accuracy to DGNSS, with positioning accuracy generally within one meter. In certain conditions, the Easting coordinate accuracy was even better, with errors of less than one meter. However, DGNSS was found to be significantly more accurate than SPP for altimetric positioning. The primary objective of this research is to develop a statistical method for evaluating the accuracy and precision of smartphone positioning, which can be applied universally since it relies solely on code pseudoranges.

2.2 Observations Period Accuracy Assessment
Bilgen et al (2022) examine the accuracy of the Precise Point Positioning (PPP) technique, a method used for absolute positioning in geodetic point positioning. The investigation involves a two-stage analysis of the root mean square errors (RMSE) of coordinates obtained from online PPP services. In the first stage, the impact of geomagnetic activity on PPP accuracy was assessed by comparing the results from three online PPP services - Automatic Precise Positioning Service (APPS), Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP), and magic Global Navigation Satellite System (magicGNSS) - during a day with high geomagnetic activity and a quiet day. The results showed that the three-dimensional (3D) RMSE was significantly higher during the high geomagnetic activity day for session durations of 1-6 hours. However, the effects of geomagnetic activity were largely mitigated when the session duration was extended to 24 hours. In the second stage, 31 days with minimal geomagnetic activity were selected, and PPP-derived coordinates were obtained from APPS, CSRS-PPP, magicGNSS, and Trimble real-time extended (RTX) for session durations of 1-24 hours. The results were compared to reference coordinates from the Australian Online GPS Processing Service (AUSPOS) and Online Positioning User Service (OPUS). The analysis revealed that increasing the session duration led to a decrease in 3D RMSE and an improvement in position accuracy. CSRS-PPP consistently yielded the best results across all scenarios.
Shakor et al (2022) investigate the impact of varying GNSS observation intervals on the convergence time and positioning accuracy of static Precise Point Positioning (PPP). The research utilizes high-rate data from 26 International GNSS Service (IGS) - Multi-GNSS Experiment (MGEX) stations, collected over three weeks in 2020. The investigation focuses on the effects of four different sampling intervals - 1, 5, 15, and 30 seconds - on the performance of static PPP. Six distinct GNSS constellations are processed, including GPS-only, GLONASS-only, Galileo-only, BeiDou-2-only, BeiDou-3-only, and multi-GNSS (combining GPS, GLONASS, Galileo, BeiDou-2, and BeiDou-3). The results demonstrate that employing higher-rate observation intervals substantially reduces the convergence time for each GNSS constellation. Notably, the maximum improvements in convergence time between 30-second and 1-second intervals are observed to be 55%, 60%, and 55% for the north, east, and up components, respectively, in the case of Galileo PPP. However, the analysis of positioning accuracy reveals that utilizing higher-rate observation intervals slightly degrades the converged positioning accuracy for each GNSS constellation, with the exception of BeiDou-3 and multi-GNSS PPP modes. Further investigation attributes this degradation in accuracy primarily to satellite clock interpolation errors, rather than orbit interpolation errors, when higher-rate observation intervals are employed. These findings have significant implications for the optimization of GNSS observation intervals in various applications, balancing the need for rapid convergence with the requirement for high positioning accuracy.

Birinci and Saka (2021) explained that, the Global Positioning System (GPS) Single Point Positioning (SPP) technique is widely utilized for navigation purposes, providing positioning accuracy at the meter level. However, the accuracy of SPP solutions is significantly influenced by various error sources, including orbital errors and satellite clock offsets. To mitigate these errors, the International GNSS Service (IGS) has focused on refining orbital and clock products since 1994. This study aimed to evaluate the performance of GPS SPP using IGS final precise products. An in-house Matlab program was developed to process the GPS data, and a ten-day dataset was analyzed. Systematic errors that degrade the accuracy of SPP solutions were identified, modeled, and removed. The weighted least squares method was employed to estimate the GPS SPP solution for each epoch.
Birinci and Saka (2021) presented their results that revealed a strong correlation between the accuracy of SPP solutions and the number of satellites visible, as well as the Geometric Dilution of Precision (GDOP) values. The positioning accuracy achieved in this study was remarkable, with a daily average accuracy of up to 21 centimeters. Moreover, the Root Mean Square Error (RMSE) values for all components were less

than 1 meter. The findings of this study underscore the significant contribution of IGS precise products to the accuracy of GPS SPP solutions. By utilizing these refined products, GPS SPP can achieve positioning accuracy at the decimeter level, making it a reliable and precise navigation technique for various applications. The methodology employed in this study demonstrates the effectiveness of using IGS final precise products for GPS SPP. The weighted least squares method proved to be a robust estimation technique for SPP solutions, and the removal of systematic errors further enhanced the accuracy of the results. Overall, this study highlights the potential of GPS SPP to achieve high positioning accuracy, making it a valuable tool for navigation and other applications.

3.0 METHODOLOGY

3.1 Study Area of Observations

The observations were carried out in part of Kogi East and Lokoja, the capital city of Kogi State, Nigeria. These areas are situated within the geographical coordinates of latitudes 07° 20' to 08° 00'N and longitudes 06° 30' to 07° 45'E. The research area encompasses several Local Government Areas like Dekina, Ofu, Ankpa, Omala, and Lokoja. These local government areas were strategically selected. The region's vegetation pattern is significantly influenced by its tropical wet and dry climate, which is characterized by a distinct rainy season and dry season (Negedu and Ono, 2024). According to Ekwedeh (2003), the vegetation spread in Kogi East follows a pattern of rainfall distribution, which is typical of the tropical wet and dry or savannah climate of AW classification. The rainy season in the study area typically starts around April and lasts till October, while the dry season usually starts from November and extends to March of the following year (Weather base, 2011). This distinct seasonal pattern has a profound impact on the region's climate, vegetation, and overall ecosystem.

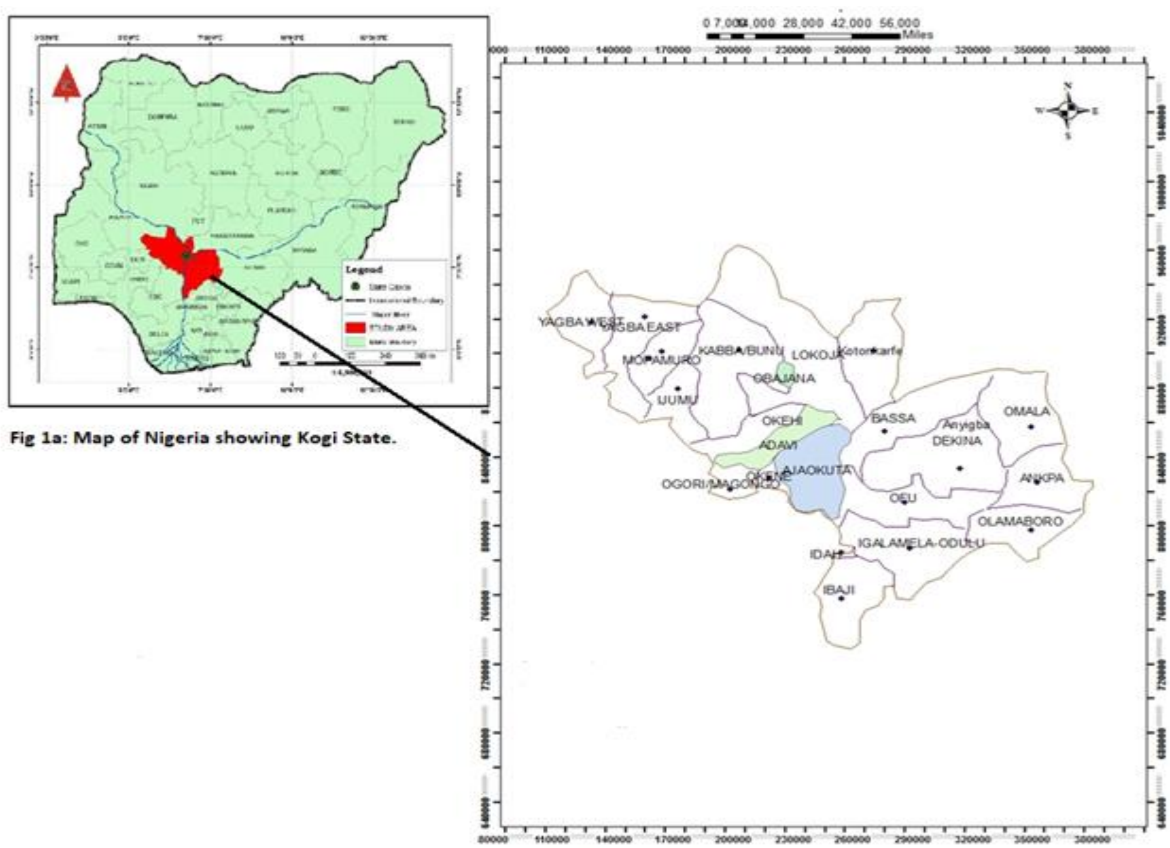

Fig 1a: Map of Nigeria showing Kogi State.

Fig 1b: Map of Kogi State showing the 21 LGAs.

3.2 Data Acquisition

Data acquisition was a crucial step in this study, and it was achieved through the use of both hardware and software instruments. The hardware components consisted of a Hi-target V.30 dual-frequency GNSS receiver, a data logger, an HP laptop, and internet facilities. These tools were essential for collecting and processing the GNSS data. Before commencing data collection, all the instruments were thoroughly tested to ensure they were functioning properly. The Hi-target V30 GNSS receiver's calibration status was verified, and temporary adjustments were made to set up, center, and level the device. The receiver's ability to track and observe satellites was also confirmed to be in excellent condition.

3.2.1 Method of Acquiring Data for CSRS-PPP
The actual data collection took place at 10 observation points, where the multi-frequency Hi-target V30 instrument was used in static mode. The signal reception was set at 30-second intervals for one hour on some stations and two hours on some. Once the satellite data observations were complete, the raw data were downloaded to a laptop using a USB cable. The raw data were then converted into RINEX format using the Hi-target Geomatics Office software. Finally, the converted data were uploaded to the CSRS-PPP online processing solution. The results were delivered to the email address.

3.2.2 Method of Obtaining the Offline SPP Data
The GNSS data were uploaded into the **Hi-Target Geomatics office software** in the absence of internet, and the raw data were instantly accessed. The project name was created, and raw GNSS data were imported into the software.

3.3 Method of processing the data
3.3.1 Processing of Raw GNSS Data Using CSRS-PPP Solution
The Hi-Target Geomatics Office software was utilized to convert the ".GNS" files into a format compatible with Precise Point Positioning (PPP), specifically the RINEX format. The converted RINEX files were then uploaded to the CSRS-PPP online Post Processing Solution via the CSRS-PPP website (webapp.geoid.nrcange.ca). The CSRS-PPP system processed the uploaded data, resolving any ambiguities associated with GPS observations. Upon completion, the processed results were returned via email to the address provided during the upload process.

3.3.2 Processing of the Range of Errors to Achieve Comparative Error Analysis
In achieving this particular objective of this study, the range between the CSRS-PPP coordinates which would serve as the reference coordinate to the offline SPP coordinates was determined. The result would thereby be seen as the range of error in both types of GNSS observation.

$$\boldsymbol{E_{range}} = \sqrt{(\Delta \boldsymbol{E}^2 + \Delta \boldsymbol{N}^2)} \qquad \textbf{1}$$

Where E_{range} the error range is $\Delta E,$ the difference between the easting value of the Precise Point positioning results obtained by CSRS and that of the offline SPP result.

3.3.3 Processing for Period of Observation Accuracy Assessment
To show the relationship between longer observation times and accuracy in the Precise Point Positioning (PPP) technique, a meticulous processing of data was undertaken by the online PPP software. The data was split into two observation periods, ranging from 1 hour to 2 hours, and PPP solutions are computed for each period.

4.0: RESULTS AND DISCUSSION
4.1 Accuracy of Processed Data
The coordinates obtained are based on the International Terrestrial Reference Frame 2014 (ITRF2014) and are tied to the ground mark. The data processing was performed by the online software and it involved several meticulous steps. A thorough data screening process followed, where weighted post-fit residuals were analyzed to detect and eliminate outliers, ensuring the integrity of the dataset. For data analysis, carrier phase data was employed with a 7-degree elevation angle cutoff and a sampling rate of 3 minutes, though data cleaning was performed at a more granular 30-second sampling rate. An elevation-dependent weighting scheme was applied to account for varying satellite positions, enhancing the accuracy of the measurements.
The IGS14 absolute phase-center variation model was applied to account for satellite antenna phase center variations. Additionally, the Global Mapping Function (GMF) was used for a priori modeling, and zenith delay corrections were estimated at 2-hour intervals using the Wet GMF mapping function. This explains why the observations that lasted 2 hours have more accuracy than those observed for just 1 hour.

To mitigate ionospheric effects, the ionosphere-free linear combination of L1 and L2 signals was formed, eliminating first-order effects while applying corrections for second and third-order effects.
By integrating these sophisticated models and techniques, the project ensured high accuracy in its measurements. The final results were based on the best available IGS data, which provided coordinates and heights of the points observed. Table 1 shows the positional uncertainty, which displays standard deviations in millimeters. The range of positional uncertainty was conducted at 95% confidence level which underscores the commitment to precision and reliability in the observations.

Table 1: Positional Uncertainty (95% C.L.) - Geodetic, ITRF2014

Station	Longitude(East) (m)	Latitude(North) (m)	Ellipsoidal Height(Up) (m)
BJ	0.036	0.237	0.104
AI	0.054	0.011	0.227
DK	0.007	0.017	0.035
KL 45	0.012	0.014	0.080
AM	0.014	0.012	0.057
0IL	0.011	0.008	0.035
Y039	0.013	0.008	0.036
Y042	0.012	0.009	0.036
FLI	0.014	0.009	0.044
02	0.010	0.008	0.030

The PPP technique used ensured that ambiguities are resolved in a baseline-by-baseline mode using the Code-Based strategy for 200-6000km baselines as seen in Table 2.

Table 2: Ambiguity Resolution

Station	Baseline	Ambiguities Resolved	Baseline Length (km)
BJ	AVERAGE	70.39%	2085.268
AI	AVERAGE	85.54%	2077.615
DK	AVERAGE	83.56%	2402.192
KL 45	AVERAGE	86.30%	1511.193
AM	AVERAGE	77.7%	2069.707
0IL	AVERAGE	56.0%	1590.903
Y039	AVERAGE	60.4%	1506.853
Y042	AVERAGE	63.8%	1825.138
FLI	AVERAGE	52.1%	1548.760
02	AVERAGE	56.1%	1590.902

4.2 Comparative Error Analysis

The range of errors in the offline Single Point Positioning (SPP) solutions was computed in relation to Precise Point Positioning (PPP) solutions. The reason is because the PPP results have had more than ambiguity resolutions. This comparison aims to quantify the differences in accuracy between these two positioning techniques. The results as tabulated in Table1 has the offline SPP values for eastings and northings for every point observed and same goes with the PPP values of the eastings and northings of the same points. It could be seen that all the observations whose duration were 1 hour respectively, had their error range between 1.67m to 3.48m. So on average, it could be seen that at 1 hour observation the offline GNSS receiver exhibited an error range of 2.5m.

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On the other hand, the 2-hour duration of observations with the same offline GNSS receivers were able to produce an error range of 0.36m to 1.18m. It was observed that observations on two stations, that is, station 02 and Y042 produce error ranges of 1.186m and 1.052m, respectively. Further investigations revealed that, there were multipath errors and poor geometry at those observation points at the time of observations. The two observation points were surrounded by canopy trees and high rise buildings. However, for other points that were performed in open and uninterrupted terrain, their error ranges were within 0.7 and 0.3m, respectively.

Table 3: The error range of the raw and unprocessed data with the post processed.

Point ID	Duration Of Observation (HOUR)	SPP (Em)	SPP (Nm)	Height	PPP (Em)	PPP (Nm)	$Height$	E_{range}
KL45	1	250773.587	859753.962	83.667	250772.155	859751.839	83.718	2.561
DEK	1	285098.951	849327.722	195.298	285097.922	849325.807	190.796	2.1745
BJ	1	335667.832	869967.159	130.063	335665.997	869965.725	128.218	2.3280
AI	1	346915.566	836333.605	407.041	346913.019	836332.355	404.273	1.6726
AM	1	297638.990	827004.512	402.556	297636.090	827002.589	399.936	3.4797
01L	2	250967.316	863113.485	83.759	250967.702	863114.092	85.927	0.7476
02	2	250956.028	863092.729	88.605	250956.925	863093.505	84.828	1.1860
FL1	2	252242.749	867891.784	71.878	252242.575	867892.103	67.581	0.3634
Y042	2	249581.358	862082.527	107.004	249581.907	862083.424	103.353	1.0520
Y039	2	250551.760	863161.127	102.849	250552.335	863160.739	98.753	0.6936

Table 4 was an extraction of Table 3, and it showed the error ranges in clear terms, and of course, Equation 1 was the source of the figures.

Table 4: Duration and range of error

PT ID	DURATION (HOUR)	ERROR (m)
KL45	1	2.561
DEK	1	2.1745
BJ	1	2.328
AI	1	1.673
AM	1	3.4797
01L	2	0.7476
2	2	1.186
FL1	2	0.3634
Y042	2	1.052
Y039	2	0.6936

4.3 Observation Period Accuracy Assessment

Table 4 revealed that, in offline Single Point Positioning (SPP), extended observation periods can indeed enhance accuracy. This improvement can be attributed to the fact that longer observation durations mitigate, though do not eliminate, noise and multipath effects. By averaging out these effects over a longer period, accuracy is improved, ultimately leading to enhanced satellite geometry.

With more observations, the satellite geometry improves, enabling better positioning and reducing atmospheric errors. The results of the analysis, as presented in Figures 1 and 2, offer valuable insights into the relationship between longer observation times and accuracy in the offline SPP technique. Upon careful consideration of the findings, the implications of the research become clear, shedding new light on the intricate relationship between observation time and accuracy in offline SPP.

Notably, the shorter bars in the figures represent smaller error values, which were obtained from 2-hour observation durations. In contrast, the longer bars correspond to 1-hour duration ranges, highlighting the improved accuracy achievable with extended observation periods. This finding underscores the importance of observation time in enhancing the accuracy of offline SPP, providing valuable guidance for practitioners seeking to optimize their positioning results

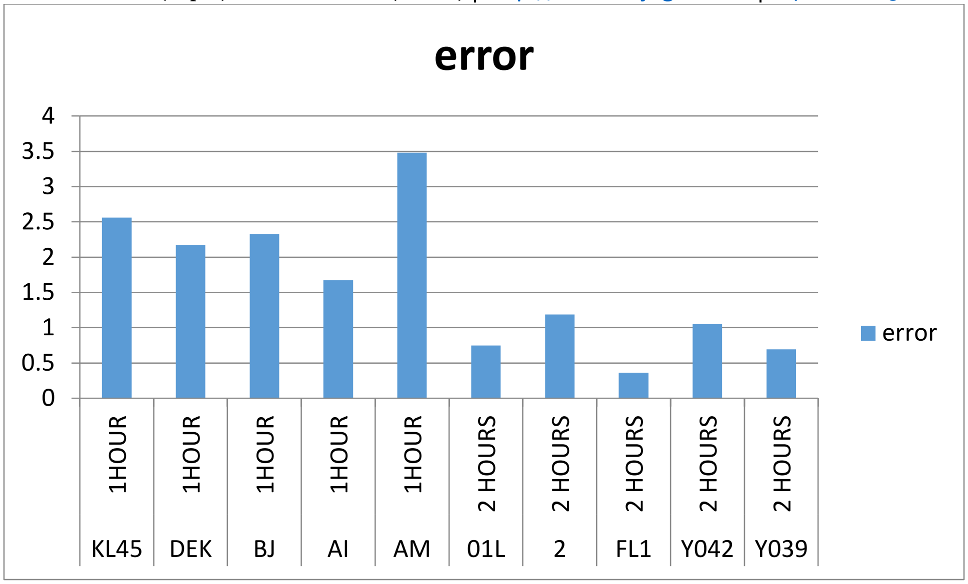

Figure 2: Accuracy vs time graph

The proximity of the data points to the center reveals a profound underlying relationship between the variables being analyzed. Notably, the two-hour observation data converges towards the center, whereas the one-hour observation data dissipates from the center. The clustering of data points near the mean suggests a strong and stable correlation between the variables, which is further reinforced by the radar error. Initially, the radar error represents the uncertainty surrounding the data for both one-hour and two-hour observations. However, as the data points converge, the radar error transforms into a visual testament to the accuracy and dependability of the results. The convergence of data points towards the center of the radar error has significant implications for decision-making processes. With the data points clustered near the mean, stakeholders can place greater trust in the results, leveraging this precision to inform critical decisions. Ultimately, this phenomenon represents a triumph of precision over uncertainty, highlighting the importance of statistical analysis in modern decision-making.

As the data points draw closer to the center, the uncertainty associated with the results diminishes, and the correlation between variables strengthens. This increased proximity suggests a more robust and stable correlation, implying that the underlying model is a faithful representation of the relationships being studied.

In contrast, the divergence of data points away from the center of the radar error represents a significant uncertainty in the results. This phenomenon highlights the power of statistical analysis in uncovering meaningful relationships and providing actionable insights, ultimately enabling stakeholders to make informed decisions with greater trust and confidence. The comparison between the one-hour and two-hour observation data reveals the importance of observation duration in achieving precise results. The convergence of data points in the two-hour observation data demonstrates the benefits of extended observation periods in reducing uncertainty and strengthening correlations. In conclusion, the convergence of data points towards the center of the radar error, as illustrated in Figure 3, represents a significant milestone in achieving precise and reliable results. This phenomenon underscores the importance of statistical analysis in modern decision-making, enabling stakeholders to make informed decisions with greater trust and confidence.

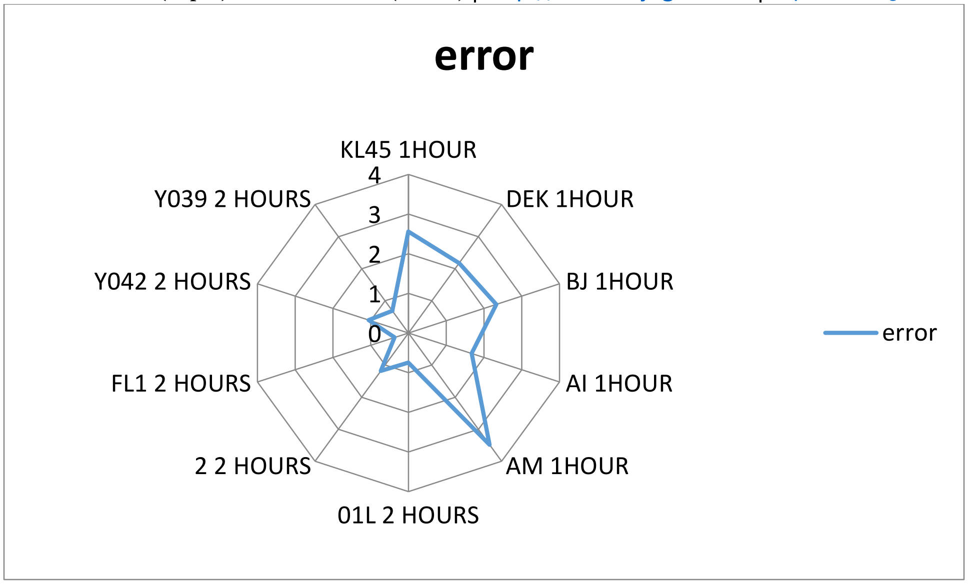

Figure 3: Error display

4.0 CONCLUSION

In conclusion, this study has demonstrated the significance of observation duration and environment on the accuracy of offline Single Point Positioning (SPP) and Precise Point Positioning (PPP) techniques using absolute GNSS receivers. The findings showed that longer observation periods, typically 2 hours, result in significantly improved accuracy, with error ranges reduced to 0.36 - 1.18 meters. Conversely, shorter observation periods of 1 hour yield larger error margins, with an average error of 2.5 meters. The study also highlights the critical role of environmental factors, such as multipath errors and poor geometry, in determining the accuracy of navigation systems. Observations conducted in open areas, devoid of obstacles and interference, yielded error ranges of 0.3-0.7 meters, underscoring the importance of optimal observation environments.

The limitation of this study to just 10 observation stations presents a notable constraint on its overall scope and reliability. With such a restricted number of stations, the study's ability to capture the full range of variations and trends is inherently limited, potentially impacting the comprehensiveness and accuracy of its findings. The conclusions drawn may not fully represent the broader context, and the study might lack the depth of insight that a more extensive dataset could provide.

To address these limitations and enhance the study's robustness, it is proposed to expand the observation network to include up to 30 stations in the next phase. This expansion would significantly improve the geographical coverage, allowing for a more comprehensive understanding of regional variations and trends. A larger network would provide a more representative dataset, reducing biases and enhancing the reliability of the findings. With more data points, the statistical power of the analysis would increase, enabling more precise detection of patterns and relationships. Furthermore, this would allow for the development of more accurate models, better capturing the complexities of the phenomena under study.

To maximize the accuracy of absolute GNSS positioning, users are recommended to adopt several key strategies. Firstly, extending observation periods to at least two hours can significantly enhance accuracy by reducing error margins. This approach enables users to achieve more precise positioning results. Another crucial factor is the observation environment. Conducting observations in open areas, free from obstacles and interference, can minimize multipath errors and poor geometry. This deliberate choice of observation location can substantially improve the reliability of positioning results.

By incorporating these techniques, users can further refine their positioning results. The geometry of satellites is another vital consideration. When conducting observations, users should prioritize better satellite geometry, as this can lead to more precise positioning. Being mindful of satellite geometry can help users optimize their positioning results.

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