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Accuracy Assessment of Smartphone-Based 2D Positioning: Checking Its Suitability for Non-Survey Geospatial Applications

Edward Pishikeni Guma[1], **Akoji Augustine Haruna**[2], **Ojonumi Felix Idoko**[4], **Abdulrasheed Salihu**[5]

[1] Department of Surveying and Geoinformatics, Kogi State Polytechnic, Lokoja, Nigeria
[2] Department of Building Technology, Kogi State Polytechnic, Lokoja, Nigeria
[3,4,5] Department of Architectural Technology, Kogi State Polytechnic, Lokoja, Nigeria
gumawelfare@gmail.com (Corresponding Author)

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Abstract
This study presents an accuracy assessment of smartphone-based 3rd-order 2D positioning and evaluates its suitability for non-survey geospatial applications. Traditional surveying relies on costly equipment, but smartphones offer a low-cost, widely accessible alternative for casual geospatial data collection. Using a Vivo Y04 with SW Maps and Geo++ RINEX Logger, data were collected at seven control points in Lokoja, Nigeria, to quantify positional accuracy under varying environmental conditions. Results show deviations from 0.337 m to 8.036 m, with environmental factors like buildings, trees, and telecom masts significantly degrading performance. Points in open fields with good satellite geometry achieved <1.0 m deviation, while obstructed sites showed larger errors. SW Maps produced more consistent results than Geo++ RINEX. The findings indicate that smartphone-based 3rd-order 2D positioning can meet accuracy requirements for non-survey applications such as rapid mapping, asset tagging, urban planning support, and environmental monitoring, where survey-grade precision is not critical. However, careful site selection and awareness of limitations are essential to minimize error. A hybrid approach combining smartphone positioning with traditional control may improve reliability. The study concludes that smartphones are a viable option for low-budget, non-survey geospatial work, and recommends further research on device models, app algorithms, and error mitigation strategies.

Keywords: Smartphone-based positioning; 3rd order 2D; accuracy assessment; geospatial data acquisition; non-survey applications; environmental factors; reliability

1. Introduction

Third-order mapping refers to the creation of maps with a horizontal accuracy of 1-3 meters, which is suitable for various applications, such as urban planning, environmental monitoring, and infrastructure development (Boarotto et al, 2020). However, Raufu et al, (2025) has established that smartphone-based 3rd order 2D surveying has the potential to provide a cost-effective and efficient solution for this mapping. Saad et al (2023) explained that the advent of smartphone technology has revolutionized various fields, including geospatial data acquisition and mapping. More so, the creation of high-resolution cameras, GPS, and inertial measurement units (IMUs) in smartphones has generated opportunities for cost-effective and efficient surveying and mapping techniques (Nowak et al, 2020).

While conventional surveying and mapping techniques achieve high levels of accuracy and precision through specialized, expensive instruments, including total stations, GNSS receivers, and aerial photogrammetry systems, the financial barrier limits their use in small-scale projects and resource-limited settings. Smartphone-based surveying addresses this limitation by capitalizing on the ubiquity and affordability of smartphones (Bori et al, 2026). The concept of using smartphones for surveying and mapping is not new as Researchers like Sarker et al (2024), Raufu et al, (2025), and others have explored its use in photogrammetry and structure-from-motion (SfM) applications.

In terms of significance, Ashraf et al. (2023) explained that the study of smartphone positioning and surveying demonstrates that a pocket device can serve as a precise measurement tool. That could access multi-constellation GNSS signals such as GPS, Galileo, BeiDou, GLONASS, including accelerometers, gyroscopes, magnetometers, and barometers. This study provides a situation whereby raw GNSS data can be obtained even at centimeter-level accuracy, which once required expensive survey equipment to obtain. It is noted also that, in civil engineering, smartphones could be used in as-built surveys and structural monitoring without mobilizing crews (Samadi et al, 2023). In agriculture, it supports precision farming and machine guidance (Michels and Oliver, 2022). It also democratizes geospatial data: citizens can map infrastructure, track environmental changes, and contribute to crowd-sourced geospatial databases (Guma et al, 2023).

This study aims to analyze smartphone-based 3rd order 2D surveying techniques for mapping and geospatial data acquisition. The objectives of this research are to; assess the accuracy of a smartphone-based 3rd order 2D surveying technique, and investigate the impact of environmental factors on the accuracy and reliability of the technique.

The remainder of this paper is organized as follows. Section 2 framework and reviews of relevant literature on smartphone-based surveying in mapping. Section 3 describes the methodology and data collection process. Section 4 presents the results and discussion, and Section 5 concludes the study with recommendations for future research.

1.1 Assessing the accuracy of a smartphone-based 3rd-order 2D Positioning

Grzadzielski and Barula (2020) did a study on raw GNSS measurements of mobile phones for high-accuracy surveying. Earlier phones used were not successful in achieving high accuracy because they could not fix ambiguities. But when they used a mobile phone that has GNSS chips built in, which can also deliver code and carrier phase measurement in post processing, hope came alive. Therefore, they used Huawei P30 Pro smartphones, which is equipped with a dual-frequency GNSS receiver that uses L1 and L5 signals. This Huawei P30 Pro smartphone was able to fix all the ambiguities in L1 signals. The results of 1-hour observation sessions were 1 - 4 cm. Also, for between 20 minutes to 30 minutes, centimetre-level accuracy was also achieved.

Gabryszuk (2020) investigated the accuracy of a smartphone-grade GNSS receiver for surveying. The study compared two different smartphones, such as Huawei P8 Lite, and iPhone 6s which have GNSS devices equipped in them. With the Huawei P8 Lite, an app known as Locus Map was used. For the iPhone 6s, the survey operation was performed using the Map-o-mater APP. The measurements made with these two phones were compared with reference coordinates.

Osborne et al (2015) did a study that compared the accuracy and precision of smartphones and handheld GNSS receivers for ecological use. The methods used were a handheld Surveyor-grade GNSS receiver which functioned as an external sensor, and smartphones with inbuilt GNSS receivers. It was discovered that the survey-grade GNSS performed significantly better with median distance estimates of between 0.5 and 1.1 m. Finally, the smartphone's built-in GNSS error gave an accuracy of between 0.9 and 3.4 m.

1.2 Investigating the impact of environmental factors on the accuracy and reliability of the technique

Hu et al (2023) investigated the limitations of precise positioning using smartphone Global Navigation Satellite System (GNSS) sensors, focusing on the quality and availability of satellite-to-smartphone ranging measurements. The authors assess the range errors in realistic environments, using a geodetic receiver as a reference, and analyze their distribution and correlation with pre-fit residuals. They analyzed smartphone GNSS range errors and found out that range errors are at their peak in suburban environments, are slightly larger in vegetation environments, and are least affected in open-sky environments; tree blockage has little impact on the measurement quality of other satellites. More so, smartphones on dashboards experience more signal suppression and interference, with range error STD values of 5.3m (first frequency) and 2.4m (third frequency), compared to roof placement (5.1m and 2.2m, respectively).

Julian et al (2017) evaluated the horizontal accuracy of smartphones for collecting spatial data in forests, comparing them to other Global Navigation Satellite Systems (GNSS) devices. The assessment was conducted at 74 points in a mixed deciduous-coniferous forest (during leaf-on and leaf-off seasons) and 17 points in open areas, using total station theodolite measurements as reference. The results show that positional accuracies of smartphones range from 4.96–11.45 m (leaf-on) and 4.51–6.72 m (leaf-off) in forests, and 1.90–2.36 m in open areas. Significant differences in accuracy were found between forest and open areas, but not consistently between leaf-on and leaf-off conditions. A survey-grade receiver outperformed all other devices, while smartphones showed comparable accuracy to mapping-grade receivers. In a separate experiment, smartphones and other GNSS devices were used to measure wind damage areas in forests, demonstrating higher accuracy than visual estimation, particularly for larger areas. The study suggests that current smartphones can be suitable for forest management tasks where high precision is not required.

Merry and Bettinger (2019) investigated the relative positional accuracy of an iPhone 6 using Avenza software in an urban environment, considering factors such as season, time of day, and WiFi usage. The results showed that the time of year had minimal impact on average horizontal position error, regardless of WiFi enablement. However, afternoon observations during the leaf-off season exhibited improved accuracy. Notably, perceived high WiFi usage periods corresponded to reduced horizontal position error, likely due to increased access points. The overall average horizontal position accuracy of the iPhone 6 (7-13 m) is comparable to recreation-grade GPS receivers in high multi-path environments, suggesting its suitability for applications requiring moderate accuracy. The findings highlight the complex interplay between environmental factors and smartphone GNSS performance, underscoring the need for further research to optimize location-based services in urban settings.

Huang et al (2022) investigated the positioning accuracy of smartphones in a deciduous forest environment, comparing them to various Global Navigation Satellite System (GNSS) devices. The study evaluated 57 test points in a mixed coniferous forest with 90% broad-leaved trees, considering different levels of openness. Results showed a significant positive correlation between canopy openness and carrier-to-noise density (C/N0). Survey-grade devices had higher C/N0 values than smartphones. Dual-frequency smartphones outperformed single-frequency ones in positioning accuracy under forest canopies. Moreover, precise-point positioning (PPP) mode improved smartphone accuracy, achieving about 2.5m horizontal accuracy in areas with high openness (R > 0.7). This is comparable to recreational-grade GNSS receivers. However, in areas with low openness (R < 0.7) and complex forest environments, survey-grade GNSS devices with PPP or real-time differential positioning methods are still necessary for sub-meter accuracy.

2. Method

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Kogi State Polytechnic, Lokoja Campus is located in Felele, Lokoja Local Government Area of Kogi State. Lokoja lies between latitudes 7° 45' 27.56'' N to 7° 51' 04.34'' N and longitudes 6°41' 55.64'' E to 6°45' 36.58'' E. It is about 165 km Southwest of Abuja as the crow flies, and 390 km Northeast of Lagos by the same measure. However, the project area is at the Staff Quarters of Kogi State Polytechnic, Lokoja campus in Lokoja L.G.A.

The rainy period of the year in Lokoja lasts for 8.8 months, from February 23 to November 16, with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered on September 4, with an average total accumulation of 7.9 inches. The rainless period of the year lasts for 3.2 months, from November 16 to February 23. The least rain falls around December 31, with an average total accumulation of 0.0 inches. The length of the day in Lokoja does not vary substantially over the course of the year, staying within 34 minutes of 12 hours throughout. In 2021, the shortest day is December 21, with 11 hours, 40 minutes of daylight; the longest day is June 21, with 12 hours, 35 minutes of daylight.

The earliest sunrise is at 6:14 AM on May 26, and the latest sunrise is 38 minutes later at 6:52 AM on January 29. The earliest sunset is at 6:10 PM on November 13, and the latest sunset is 44 minutes later at 6:55 PM on July 14. Daylight saving time (DST) is not observed in Lokoja during 2021. The topography within 2 miles of Lokoja contains very significant variations in elevation, with a maximum elevation change of 1,266 feet and an average elevation above sea level of 277 feet. Within 10 miles also contains very significant variations in elevation (1,637 feet). Within 50 miles contains very significant variations in elevation (2,126 feet).

The area within 2 miles of Lokoja is covered by grassland (23%), water (22%), trees (21%), and cropland (15%), within 10 miles by shrubs (43%) and cropland (29%), and within 50 miles by shrubs (44%) and cropland (30%).

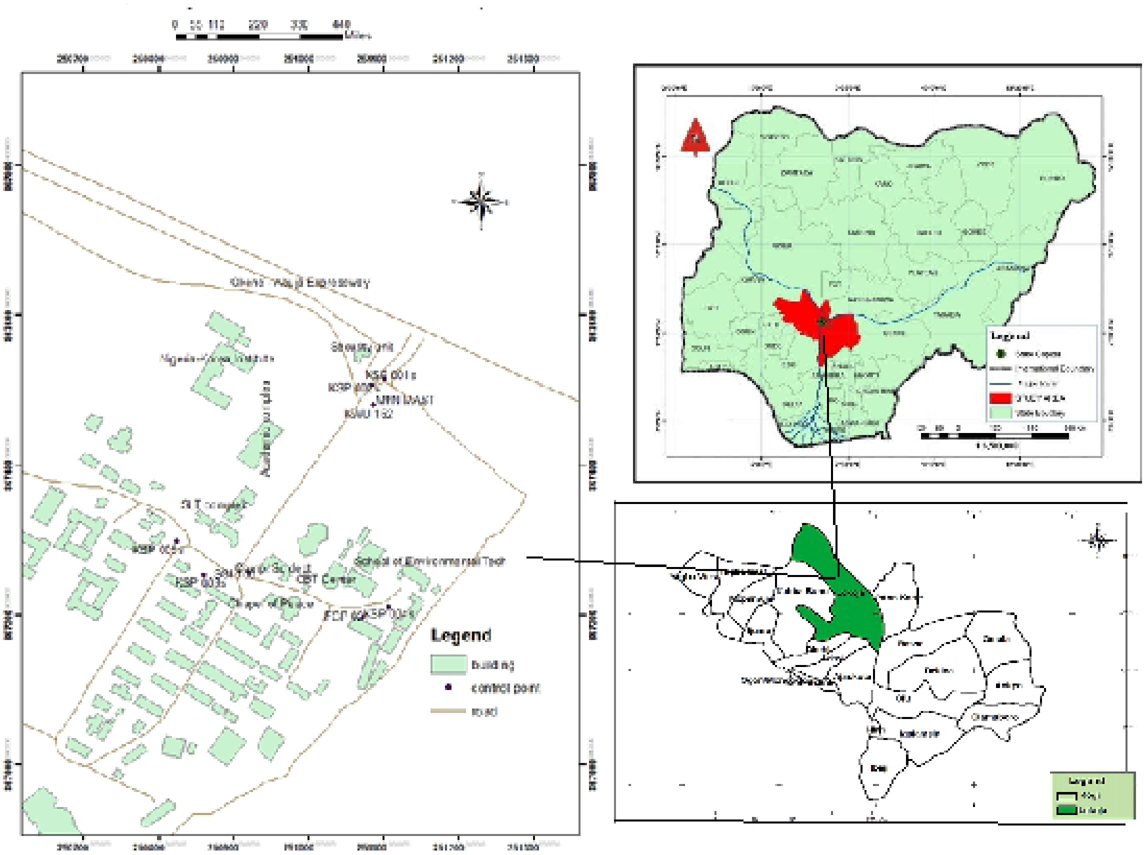

Figure 1: Map of Nigeria showing Kogi State and the study area.

3.2 Instrument Requirement

The primary data acquisition was done by a smartphone, funtouch OS 15, model V2430. The phone product is Vivo Y04. The secondary data used was obtained using Hi-Target V30 GNSS receiver. The software used for the primary data are; SW Maps version 3.0.14.3 developed by Avinab Malla of Aviyaan Tech (P) Ltd., and Geo ++ RINEX Logger 2.1.8. For the secondary data, the Hi-Target GNSS receiver observation results were collected. The observation had been carried out for close to four years now, with the coordinate values readily available at the archive of the Department of Surveying and Geoinformatics. The reason the Vivo mobile phone was used was because it is equipped with a GNSS chipset (Vivo, 2026)

3.3 Method of data collection

3.3.1 Primary data collection

The SW Maps software was launched on the phone, and the "REC" icon was touched to display the "record feature". When the "record feature" was touched, the point ID was labelled, and the reading was ticked at "averaging". While it is acquiring the GNSS signal, it is also displaying the result in real time. The observation was left for 30 minutes. So that cycle slip can be taken care of. Same was done for the Geo ++ RINEX Logger 2.1.8, whereby raw data are automatically received and stored in RINEX format. The similarity between this method and that of a standalone receiver is that they both need their raw data in a RINEX file. The Geo ++ method has its RINEX already converted. No need for software to convert to RINEX. The SW Maps software/App collects its data in real time and supports high accuracy.

The acquired data were exported in CSV format, which allows for further analysis and probably integration. Whereas, the data for Geo ++ RINEX were uploaded to an online post-processing platform, the Canadian spatial reference system (CSRS) for processing.

3.3.2 Method of secondary data acquisition

The secondary data used were obtained from the archive of the Department of Surveying and Geoinformatics. The accuracy of the observations was shown in Guma et al (2023) to be 0.262 m in the easting coordinate and -0.263 m in the northing coordinate, respectively; and the Euclidean distance accuracy is 0.371m. Table 1 contains the reference coordinates (PPP) of control points KSP 004s, SGI 100, KWU 1622, KSP 001, KSP 002, KSP 005s, and FGP 021 as obtained from the archive.

Table 1. PPP coordinates as obtained from the archive of the Department of Surveying & Geoinformatics, Kogi State Polytechnic, Lokoja, Nigeria.

PT ID	PPP (Reference)	
	Easting (m)	Northing (m)
KSP 004s	251025.296	867330.871
SGI 100	250850.202	867374.709
KWU 1622	250982.748	867571.404
KSP 001	251028.070	867636.008
KSP 002	250984.348	867603.958
KSP 005s	250738.546	867411.911
FGP 021	250997.845	867316.845

Source: Guma et al (2023).

3. Results and Discussion

3.1 Result and discussion on assessing the accuracy of a smartphone-based 3rd-order 2D Positioning

The coordinates as obtained from the SW Maps app and Geo++ RINEX are all displayed in Table 2. The coordinates are displayed side by side with the PPP control values that are used as reference for the SW Maps and Geo++ RINEX Apps.

Table 2: Coordinates from the various platforms

PT ID	PPP (Reference)		SW Maps App		Geo++ RINEX	
	Easting (m)	Northing (m)	Easting (m)	Northing (m)	Easting (m)	Northing (m)
KSP 004s	251025.296	867330.871	251025.001	867330.161	251024.139	867330.653
SGI 100	250850.202	867374.709	250849.624	867374.397	250846.796	867377.843
KWU 1622	250982.748	867571.404	250981.584	867572.411	250980.199	867571.626
KSP 001	251028.070	867636.008	251020.804	867639.441	251028.936	867633.651
KSP 002	250984.348	867603.958	250984.011	867603.953	250983.233	867607.576
KSP 005s	250738.546	867411.911	250735.763	867411.456	250737.348	867408.449
FGP 021	250997.845	867316.845	250995.047	867318.872	NOT	NOT

Table 3 presents the coordinate errors in Easting and Northing for the seven control points derived from SW Maps and Geo++ post-processing relative to reference coordinates. The results show that SW Maps produced predominantly negative easting errors, with magnitudes ranging from -0.295 m at KSP 004s to -7.266 m at KSP 001, suggesting a systematic westward bias. In contrast, Geo++ errors exhibited greater variability and less consistent direction, with ΔE ranging from -3.406 m to 0.866 m and ΔN from -3.462 m to 3.618 m.

Table 3: Coordinate errors (m)

PT ID	SW Maps ΔE	SW Maps ΔN	Geo++ΔE	Geo++ΔN
KSP 004s	-0.295	-0.710	-1.157	-0.218
SGI 100	-0.578	-0.312	-3.406	3.134
KWU 1622	-1.164	1.007	-2.549	0.222
KSP 001	-7.266	3.433	0.866	-2.357
KSP 002	-0.337	-0.005	-1.115	3.618
KSP 005s	-2.783	-0.455	-1.198	-3.462
FGP 021	-2.798	2.027	-	-

The statistical summary in Table 4, based on n=6 after excluding FGP 021 due to missing Geo++ data, confirms this pattern for SW Maps, yielding a mean easting error of -2.454 m and a mean northing error of 0.833 m. The standard deviations of 2.617 m and 1.841 m for easting and northing, respectively, indicate moderate precision, while the computed 2D RMSE of 4.019 m reflects overall horizontal accuracy. This level of accuracy positions SW Maps within mapping-grade GNSS performance, but the systematic easting bias and RMSE >4 m limit its suitability for survey-grade or cadastral applications without site-specific calibration. The large outlier at KSP 001 is definitely attributed to local multipath effects and, by extension, a poor satellite geometry during data capture, underscoring the influence of environmental conditions on smartphone GNSS accuracy.

Table 4: Statistical analysis – SW Maps APP vs PPP, n=6

Component	Mean error (m)	Std Dev. (m)	RMSE (m)	95% CONFIDENCE
Easting	-2.454	2.617	3.512	-2.454
Northing	0.833	1.841	1.953	0.833
2D Horizontal	-	-	4.019	-

$$RMSE\ 2D = \sqrt{RMSE_E^2 + RMSE_N^2} = \sqrt{3.512^2 + 1.953^2} = 4.02\ m$$

Table 5 presents the statistical accuracy of Geo++ RINEX post-processing relative to PPP for n=5 control points. Geo++ achieved a mean easting error of -1.672 m and a mean northing error of 0.268 m, with standard deviations of 1.435 m and 2.813 m, respectively. The resulting 2D RMSE was 3.467 m, which is lower than the 4.019 m RMSE reported for SW Maps in Table 4. This indicates that Geo++ provides higher overall accuracy, primarily due to reduced influence from large outliers such as the -7.266 m easting error observed for KSP 001 in SW Maps, as RMSE penalizes large deviations more heavily. In terms of precision, Geo++ demonstrated better consistency in easting with a standard deviation of 1.435 m compared to 2.617 m for SW Maps, suggesting more stable performance in the east-west component.

However, SW Maps showed better precision in northing with a standard deviation of 1.841 m versus 2.813 m for Geo++. The presence of a residual easting bias in both methods, -2.454 m for SW Maps and -1.672 m for Geo++, implies systematic error sources common to smartphone GNSS, such as antenna phase center offsets or unmodeled atmospheric delays. Thus, while Geo++ outperforms SW Maps in overall 2D accuracy and easting precision, neither method meets survey-grade requirements, and component-wise performance varies depending on the metric emphasized.

Table 5: Geo++ RINEX vs PPP, n=5

Component	Mean error (m)	Std Dev. (m)	RMSE (m)	95% CONFIDENCE
Easting	-1.672	1.435	2.149	-1.672
Northing	0.268	2.813	2.720	0.833
2D Horizontal	-	-	3.467	-

The accuracy of the results were analyzed using the already existing PPP coordinates for the various points which these apps and software were observed on. The said PPP coordinates were observed and used by Guma et al (2023). In assessing the accuracy, the SW Maps coordinates were used to determine the range from the PPP coordinates and the same procedure was carried out for Geo++ RINEX coordinates as can be seen in table 2. The table 2 has its first row as PPP coordinates against the SW Maps coordinates. By interpretation, the control point has a range value of 0.769 m, which means the deviation from the reference point is that figure. Looking at the environment, there are no obstructions to signals signifying the absence or little of multipath errors. The satellite geometry could be adjudged to be good. The range value of 0.657 m was obtained for control SGI 100, which explained the condition of the surrounding of the control. There are little obstructions in the area. The satellite signals received at that moment are; GPS: C1 and GLONASS: C1.The geometry is averagely good because when the controls were first coordinated four years ago, there were not some trees and structures as there are at the moment of this study.

For KSP 002s, the satellite processed are GPS: C1 L1 and GLONASS: C1 L1. The result of the range is 0.337 m, which shows that the deviation from the PPP coordinate of the control is lesser. The geometry of the satellite is much good. KSP 001s is located outside of the campus gate and so close to the fence of the institution. The visible challenge about this control is the fact that Multipath presence is a great setback. Control KWU 1622 has a deviation of 1.172m which could be attributed to interference from a nearby telecommunications mast. The Control point FGP 021 records the second to the highest deviation from the reference point with a value of 5.753 m. At this point, there are now canopy trees that visibly affect satellite signal reception.

The values obtained using the Geo ++ app were never encouraging, as none of them could be practically used for surveying. The app needs to define the minimum time of observations needed to achieve the required accuracy for at least 3rd order surveying. Table 2, the second row shows the results.

3.2 Discussion on investigating the impact of environmental factors on the accuracy and reliability of the technique

Table 6 compares the 2D positional deviation of SW Maps and Geo++ RINEX from PPP reference coordinates, and the variability across points highlights the strong influence of environmental factors on GNSS accuracy. Most points show relatively low deviations for both methods, e.g., KSP 002 at 0.337 m for SW Maps and 1.177 m for Geo++ at KSP 004s, indicating good performance under open-sky conditions with minimal obstruction. However, large deviations at specific points reveal site-dependent effects: KSP 001 shows an 8.036 m error for SW Maps compared to 2.511 m for Geo++, and SGI 100 reaches 4.628 m for Geo++ versus 0.657 m for SW Maps. Such discrepancies are characteristic of multipath interference, where signals reflect off nearby structures, vegetation, or terrain, causing signal distortion that affects post-processing algorithms differently. Similarly, FGP 021 was not processed by Geo++, which may reflect poor satellite geometry or signal obstruction at that location, reducing the number of usable epochs. The inconsistent performance between SW Maps and Geo++ across points further suggests that environmental conditions like canopy cover, building proximity, or ionospheric disturbances interact with each app's processing model and correction source. Thus, while both smartphone apps can achieve sub-meter accuracy under favorable conditions, accuracy degrades significantly in obstructed or reflective environments, emphasizing that GNSS observation quality is as dependent on the local environment as it is on the processing method.

Table 6: The total deviation from PPP controls between SW Maps and Geo++ RINEX

POINT ID	PPP (Reference) Vs SW Maps r = $\sqrt{(E_{PPP} - E_{SW\ Map})^2 + N_{PPP} - N_{SW\ Map})^2}$ (m)	PPP (Reference) Vs Geo ++ r = $\sqrt{(E_{PPP} - E_{Geo++})^2 + N_{PPP} - N_{Geo++})^2}$ (m)
KSP 004s	0.769	1.177
SGI 100	0.657	4.628
KWU 1622	1.172	2.558
KSP 001	8.036	2.511
KSP 002	0.337	3.786
KSP 005s	2.820	3.663
FGP 021	5.753	NOT PROCESSED

4. Conclusion

4.1 Conclusion

Though this study is a research in progress, the study evaluated the accuracy and reliability of smartphone-based 3rd-order 2D positioning for mapping and geospatial data acquisition. The results showed that environmental factors such as buildings, trees, and telecommunication masts significantly impact the accuracy of satellite surveying. Control points in open fields with good satellite geometry achieved deviations of less than 100cm, while those near obstacles showed larger discrepancies. The SW Maps app demonstrated more reliable results compared to Geo++ RINEX, but both apps require careful consideration of environmental factors to ensure optimal accuracy. A hybrid approach combining satellite surveying with traditional methods like Total Stations or Theodolites can help achieve reliable and accurate data. The study highlights the potential of smartphone-based surveying as a cost-effective alternative for mapping and geospatial data acquisition, particularly for small-scale projects or applications with limited budgets. However, it also underscores the need for careful planning and selection of survey locations to minimize errors. The findings of this study have implications for various applications, including urban planning, environmental monitoring, and infrastructure development. By understanding the limitations and capabilities of smartphone-based surveying, professionals can leverage this technology to achieve accurate and reliable geospatial data.

4.2 Recommendation

This research is still work in progress, and it is hereby recommended that future research include investigating the impact of different smartphone models and surveying techniques on accuracy, as well as developing strategies to mitigate environmental interference; also, more observation stations will be considered. Overall, this study demonstrates the potential of smartphone-based 3rd-order 2D positioning as a viable alternative for geospatial data acquisition.

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