Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 202 (2025) 65-77 EISSN 2392-2192

Accuracy and Reliability of Smartphones GNSS Applications: A Comparative Study with Handheld GPS Device for Position Determination

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ABSTRACT

Advances in technology have led to the widespread adoption of Smartphone GPS for position determination, yet many users are unaware of their accuracy. This study aims to compare Android GPS applications on three smartphones (Samsung, Tecno, Infinix) and handheld GPS with the existing standard (DGPS). The study employed mobile topographers embedded in smartphones to acquire coordinates from existing survey beacons in three modes (airplane, offline, and online). Data were also collected using handheld GPS at the same control beacons. Fifteen (15) stations were observed, and the acquired data were compared to determine the accuracy of the observations. The results of the analysis revealed a significant difference between the smartphone data and DGPS, with error ranging from 2 to 15 m for DGPS and 0.2 to 10 m for handheld GPS, depending on the observation modes. Notably, the Samsung S8 smartphone exhibited superior accuracy compared to other smartphones, achieving standard deviations of 2.188 m, 1.475 m, and 1.826 m in airplane, offline, and online modes, respectively. The ANOVA test conducted at 95% confidence level, however, revealed that the smartphones and handheld GPS observed distance did not differ significantly. Based on these findings, Samsung can be used as a reliable alternative to a dedicated handheld GPS for acquiring horizontal positions.

(Received 10 January 2025; Accepted 15 March 2025; Date of Publication 9 April 2025)

These results highlight the potential of smartphones in surveying applications, however, further research is needed to ensure their optimal integration and address their current limitations in accuracy.

Keywords: Handheld GPS, Smartphone GPS, Accuracy, Samsung, Tecno, Infinix

1. INTRODUCTION

Smartphones have become a universal tool that accompany people in their daily activities. These devices have become an integral part of the human race, widely adopted and used by a large segment of the population. Whether it is for communication, navigation, accessing information, or engaging in various applications and services, smartphones have seamlessly integrated into our lives (Dabove et al., 2020). Smartphones are equipped with various sensors, including Global Navigation Satellite System (GNSS) chipsets, altimeter, accelerometer, gyroscopes, cameras, etc., enabling users to determine their precise location and compute their position (Chen & Chen, 2021; Szot et al., 2019; Dabove et al., 2017). The combination of these components, along with the innovation of mobile app developers, has led to a vast selection of applications that are accessible to users, either for free or for a fee. Due to its dominant market share of 85%, the Android operating system has emerged as the primary platform for application and device development (Szot et al., 2019). Consequently, a majority of applications and devices are designed and optimized specifically for the Android platform.

The availability and accuracy of global and local satellite navigation systems have opened up countless possibilities for innovative solutions across various industries and sectors (Weng et al., 2020; Szot et al., 2019; Korpilo et al., 2017; Wang et al., 2013). These systems serve as the foundation for a wide range of functionalities and services. Whether it is navigation and routing applications, or location-based services, satellite navigation systems play a pivotal role in enabling these applications to function effectively. Most modern smartphones receive signals from Global Positioning System (GPS), GLONASS, Galileo, and BeiDou constellations, which aids in navigation, location of positions, and reading maps (Gogoi et al., 2018). Leveraging multiple satellite navigation systems simultaneously offers significant advantages, including faster positioning and enhanced accuracy in determining the position (Szot et al., 2019; Specht et al., 2018) by mitigating the impact of individual system errors and increasing the redundancy of measurements. As a result, users can experience faster and more precise positioning outcomes, contributing to improved performance across various applications and domains.

The advantages of GNSS technology are noteworthy, particularly in the context of positioning using smartphones, handheld devices, and low-cost GNSS receivers (Bakula et al., 2022). There has been a significant surge in interest in this area. Numerous scientists have directed their attention towards exploring the potential of GNSS observations obtained from mobile phones (Realini et al., 2017; Dabove & Di Pietra, 2018). The latest generation of smartphones and mass-market portable receivers equipped with built-in GNSS chipsets have demonstrated remarkable positioning accuracy and quality (Bakula et al., 2022). In a study conducted by Kos et al. (2013), the positioning performance of two Samsung mobile devices was evaluated by comparing the determined position of a fixed point with the measurements obtained from a differential GPS system. The study found that the first device exhibited a standard deviation of 3.374 m, while the second device had a standard deviation of 4.735 m. Based on these results, the study concluded that the deviations observed in the positioning accuracy of the devices did not meet the satisfactory requirements for safe navigation, particularly considering the growing prevalence of smartphone usage among users relying on navigation applications.

In another study conducted by Merry & Bettinger (2019), the accuracy of iPhone 6 smartphone for position determination in urban environment was evaluated. The study revealed that the overall average horizontal position accuracy of the iPhone 6 device fell within the range of 7 to 13 m.

In a study conducted by Zandbergen (2009), the accuracy of a 3G iPhone smartphone for the collection of location data in three different modes (Assisted GPS, WiFi, and cellular positioning) was examined. The results obtained showed that the Assisted GPS locations obtained using the 3G iPhone were much less accurate than those from regular autonomous GPS units, with an average median error of 8 m. Additionally, WiFi locations using the 3G iPhone were also found to be much less accurate, with a median error of 74 m. Among the three modes, cellular positioning using the 3G iPhone was determined to be the least accurate, exhibiting a median error of 600 m. Dabove & Petovello (2014) also evaluated the accuracy of two smartphones, the Samsung Galaxy S5 and iPhone 4, for positioning in both urban canyon and open area environments. The results obtained showed that the Samsung Galaxy S5 performed better in both urban canyon and open area environments, exhibiting a standard deviation of 6.51 m and 3.61 m in horizontal position, respectively, compared to the iPhone 4 with a standard deviation of 9.56 m and 3.66 m. The study concluded that the accuracy of smartphone positioning is mainly dependent on the environment, including factors such as obstacles, satellite visibility, and multipath effects. In a study conducted by Lachapelle et al. (2018), comparison of the performance of a hand-held GNSS Garmin GPSmap 66 unit and a Huawei P10 smartphone under various conditions, including on a building rooftop, in an urban canyon, indoors, and in a car, was conducted. The findings revealed that the GPSmap 66 exhibited relatively better performance compared to the Huawei P10. This superiority was attributed to the GPSmap 66's lower gain advantage over the P10. In their research, Aggrey et al. (2020) examined the effectiveness and performance of precise point positioning (PPP) with different smartphones, namely Xiaomi Mi8, Huawei Mate 20, Google Pixel 3, and Samsung Galaxy S9. The result obtained revealed that the horizontal error, both in static and kinematic scenarios, varied from decimeter-level to meter-level accuracy.

With the increasing integration of GNSS applications into smartphones, there is a growing interest in determining whether these devices can serve as viable alternatives to dedicated handheld GPS receivers for geospatial applications (Merry & Bettinger, 2019). While smartphone GNSS technology has improved, questions remain about its accuracy and reliability compared to commercially available mapping-grade devices. Surveyors, engineers, and geoscientists require precise positional data for their work, and understanding the performance limitations of smartphone-based GNSS solutions is crucial. This study aims to evaluate the positional accuracy and reliability of three smartphones (Infinix, Tecno, and Samsung) equipped with GNSS applications. By comparing smartphone positioning results with handheld GPS receivers and differential GPS data, we seek to determine the extent to which smartphones can be used for surveying applications and whether they can replace dedicated handheld GPS devices in various observation modes.

2. MATERIALS AND METHOD

2.1. Study Area

The study area is the campus of the Federal University of Technology Akure (FUTA), which is geographically positioned between latitude 7° 18’ 07.80” N to 7° 17’ 46.92” N and longitude 5° 08’ 24.06” E to 5° 08’ 45.42” (Tata et al., 2020). The university is situated in Akure, the capital city of Ondo State, specifically within the Akure South Local Government Area, as shown in Figure 1.

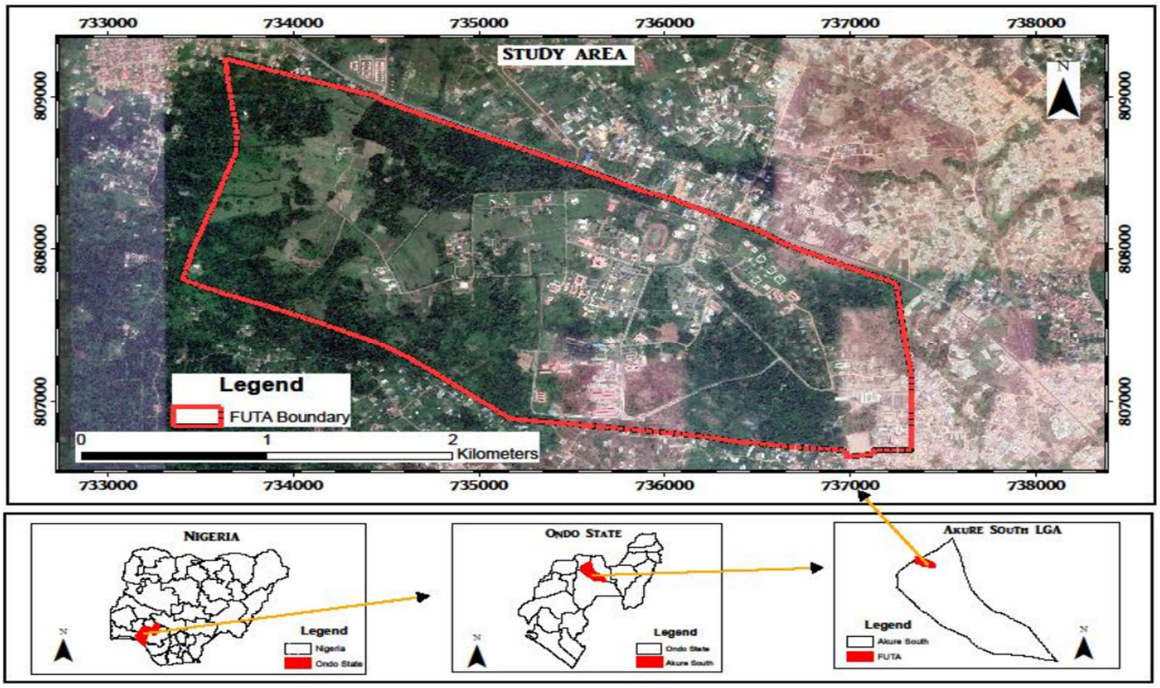

Figure 1. Study area (Tata and Olatunji, 2021; Tata et al., 2020).

2.2. Data

In order to achieve the objective of this study, both primary and secondary data were utilized. The primary data consisted of the horizontal coordinates of control points acquired through the use of smartphones and handheld GPS devices. Selected technical considerations regarding the smartphones can be found in Table 1. On the other hand, the secondary data encompassed the horizontal coordinates of fifteen (15) selected control points provided by the Department of Surveying and Geoinformatics, FUTA, which were established using DGPS technology.

Table 1. Technical considerations of selected smartphones.

Smartphone	Released year	GNSS constellation				RAM
		GPS	GLONASS	GALILEO	BEIDOU	
Tecno spark plus (Tekno K9)	2017	+	-	-	-	2 GB
Infinix (Note 7)	2020	+	-	-	-	4 GB
Samsung galaxy (S8)	2017	+	+	+	+	4 GB

2.3. Data Acquisition

For the acquisition of the primary data, a cutting-edge Android application called Mobile Topographer was employed and installed on the smartphones under study. The app, specifically version 7.8.3, incorporates advanced techniques to enhance the accuracy of the smartphone's measurements. To ensure compatibility, a GNSS receiver is integrated into this survey application and offers the flexibility to switch between geodetic and Cartesian coordinate systems. Figure 2 shows the application interface, providing the northing and easting coordinates.

Figure 2. Mobile Topographer application interface.

To ensure data accuracy, redundant measurements were performed at each station. Additionally, weather conditions played a crucial role, with observations avoiding periods of intense sunlight or thick cloud cover that could adversely affect the devices used. The compatibility of the application on the smartphones was also thoroughly tested. Furthermore, all observation devices were carefully set to ensure they were operating within the same coordinate system, specifically the Minna 2008 datum.

The app was launched on the smartphones, which were then placed on existing control stations. The survey was initiated, and the UTM Minna 2008 Datum was selected as the coordinate system, as the secondary data used as the reference base was also in Minna 2008 Datum. Each point was observed for a duration of five minutes, and the process was repeated three times at the same point for consistency. Three different observation modes were employed for each phone: airplane mode (no network coverage), offline mode (with cellular network but no internet access), and online mode (with internet access).

These three modes of observation were conducted on each of the three phones (Samsung, Tecno, and Infinix) at every selected station. The information obtained during the observation was recorded in a field note for subsequent processing. Additionally, the handheld GPS device (Garmin 72H) was utilized to observe the stations three times consecutively, and their coordinates were recorded in a separate field note.

2.4. Data Analysis

The accuracy and reliability of smartphone GNSS applications and a handheld GPS receiver were evaluated by comparing their horizontal position measurements with DGPS data. The analysis was conducted under three different observation modes: airplane mode, offline mode, and online mode.

To assess the precision of each device, standard deviation was used to measure the variability in horizontal positioning. Additionally, a one-way Analysis of Variance (ANOVA) was performed to determine whether there were significant differences in positional accuracy among the different devices and observation modes. Following the ANOVA, a Tukey post-hoc test was conducted to identify which specific device or observation mode exhibited statistically significant differences in accuracy when compared to others. This statistical approach provides insight into the performance variations across the different GNSS receivers and helps determine the suitability of smartphones for precise positioning applications.

3. RESULTS AND DISCUSSION

The results obtained from this study are the 2-dimensional positions of fifteen (15) existing control points, which were established using DGPS and the observed coordinates of the station using both handheld GPS receiver and three smartphones equipped with GNSS applications in three different modes. The differences between the DGPS coordinates and those obtained from the handheld GPS and each smartphone were calculated, and the accuracy of each smartphone was assessed based on the standard deviation using SPSS statistics software. A smaller standard deviation indicates a higher accuracy in the horizontal position obtained from the smartphone. Tables 2 to 4 present the horizontal position errors, indicating the differences between the DGPS coordinates and those obtained from the handheld GPS device and the smartphones observations in airplane, offline, and online mode.

Table 2. Handheld GPS and smartphones horizontal position errors in airplane mode.

Station	Handheld GPS Error (m)	Smartphone		
		Tecno K9 Error (m)	Infinix Note 7 Error (m)	Samsung S8 Error (m)
SVG/G15/22	7.082	9.937	9.734	7.431
SVG/G13/07	7.849	11.273	7.027	9.507
SVG/G13/06	6.354	11.861	7.553	9.051
SVG/G13/05	6.881	11.004	4.267	7.029
FUTA/GPS1	9.861	9.886	8.736	8.721
SVG/G15/27	8.759	10.576	6.908	10.315
SVG/G15/25	1.054	9.632	7.306	8.747
SVG/G15/23	10.276	3.907	8.736	15.413
SVG/G17/58	9.971	12.067	9.428	9.422
SVG/G17/57	12.249	8.023	10.293	7.880
SVG/G16/29	9.122	8.056	10.605	9.149
SVG/G17/56	6.838	6.801	12.981	7.038
SVG/G17/55	6.439	6.484	12.252	11.772
SVG/G15/21	8.111	5.013	11.819	7.190
SVG/G15/20	5.533	4.417	10.035	7.847
Standard deviation (m)	**2.598**	**2.735**	**2.326**	**2.188**

Table 3. Handheld GPS and smartphones horizontal position errors in offline mode.

Station	Handheld GPS Error (m)	Smartphone		
		Tecno K9 Error (m)	Infinix Note 7 Error (m)	Samsung S8 Error (m)
SVG/G15/22	9.083	8.316	9.217	7.544
SVG/G13/07	9.731	7.947	6.944	8.728
SVG/G13/06	6.830	9.671	9.847	8.684
SVG/G13/05	6.992	10.560	10.047	7.642
FUTA/GPS1	8.088	9.974	7.281	6.247
SVG/G15/27	5.350	10.377	6.920	9.697
SVG/G15/25	11.310	10.432	8.339	10.132
SVG/G15/23	9.714	4.559	10.966	11.875
SVG/G17/58	7.487	10.784	11.707	11.038
SVG/G17/57	12.436	10.160	7.867	8.221
SVG/G16/29	10.992	8.482	7.899	8.870
SVG/G17/56	7.920	3.627	11.995	8.885
SVG/G17/55	7.652	7.737	9.028	10.527
SVG/G15/21	7.255	3.756	10.635	8.595
SVG/G15/20	11.247	2.547	11.658	7.790
Standard deviation (m)	**2.033**	**2.882**	**1.779**	**1.475**

Table 4. Handheld GPS and smartphones horizontal position errors in online mode.

Station	Handheld GPS Error (m)	Smartphone		
		Tecno K9 Error (m)	Infinix Note 7 Error (m)	Samsung S8 Error (m)
SVG/G15/22	7.778	7.250	12.654	7.902
SVG/G13/07	8.481	9.081	5.444	6.659
SVG/G13/06	7.328	9.435	8.636	7.956
SVG/G13/05	7.700	10.098	8.668	9.343
FUTA/GPS1	6.291	11.727	9.506	8.045
SVG/G15/27	5.350	11.206	6.700	10.354
SVG/G15/25	9.088	9.473	9.478	12.237
SVG/G15/23	11.010	6.365	10.697	7.969
SVG/G17/58	8.301	8.821	11.633	10.608
SVG/G17/57	11.893	10.127	10.273	8.712
SVG/G16/29	8.665	8.528	12.237	7.173
SVG/G17/56	7.932	5.799	7.782	6.414
SVG/G17/55	8.001	7.893	13.473	8.882
SVG/G15/21	7.255	3.958	11.236	4.916
SVG/G15/20	11.106	2.278	10.663	7.507
Standard deviation (m)	**1.780**	**2.623**	**2.235**	**1.826**

Figure 3 shows visually plots of three stations out of the fifteen (15) GCPs observed with the smartphone, comparing their positions to the DGPS and handheld GPS points. Each point is represented by a circle, and different colours distinguish the plotted data: black for DGPS positions, purple for handheld GPS receiver, yellow for Samsung S8, blue for Tekno K9, and red for Infinix Note 7 coordinates.

Figure 3 illustrates that the observations made with the smartphones show minimal deviation from the handheld GPS observations. The clustering of smartphone observations around the handheld GPS points demonstrates their close alignment. Notably, compared to previous research by Zandbergen (2009), there has been a remarkable improvement in smartphone GPS error, with each smartphone showing an error ranging from 2 - 15 m when compared to DGPS positions and 0.2 - 10 m when compared with handheld GPS data.

Furthermore, a significant number of handheld GPS and smartphone positions plotted in Figure 3 fell towards the south-east of the DGPS data. This intriguing pattern could potentially be utilized in further research to develop accurate position determination with smartphones. Calculating a constant to be added or subtracted from the smartphone observations might help refine their positional accuracy.

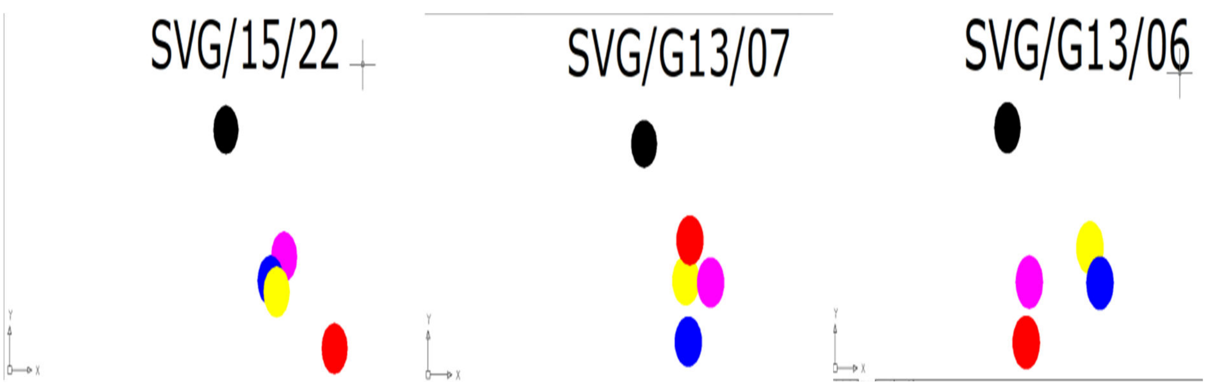

Figure 3. Comparison of smartphone positions with DGPS and handheld GPS coordinates.

Figure 4 depicts the summary of horizontal positioning standard deviation comparisons among the three smartphones and the handheld GPS receiver. It is evident that the Samsung S8 smartphone exhibits superior accuracy compared to other two smartphones. In airplane, offline, and online modes, the Samsung S8 achieved standard deviations of 2.188 m, 1.475 m, and 1.826 m, respectively. This improved accuracy can be attributed to the GNSS chip embedded in the smartphone, which can receive signals from GNSS satellites. The Tekno K9 smartphone exhibited the maximum deviation with standard deviations of 2.735 m, 2.882 m, and 2.623 m in the three modes. Furthermore, the Samsung S8 smartphone demonstrates superior accuracy compared to the handheld GPS in airplane and offline modes, and it shows comparable accuracy in the online mode. These results suggest that the Samsung S8 smartphone GNSS could serve as a reliable alternative to a dedicated handheld GPS receiver for acquiring horizontal positions.

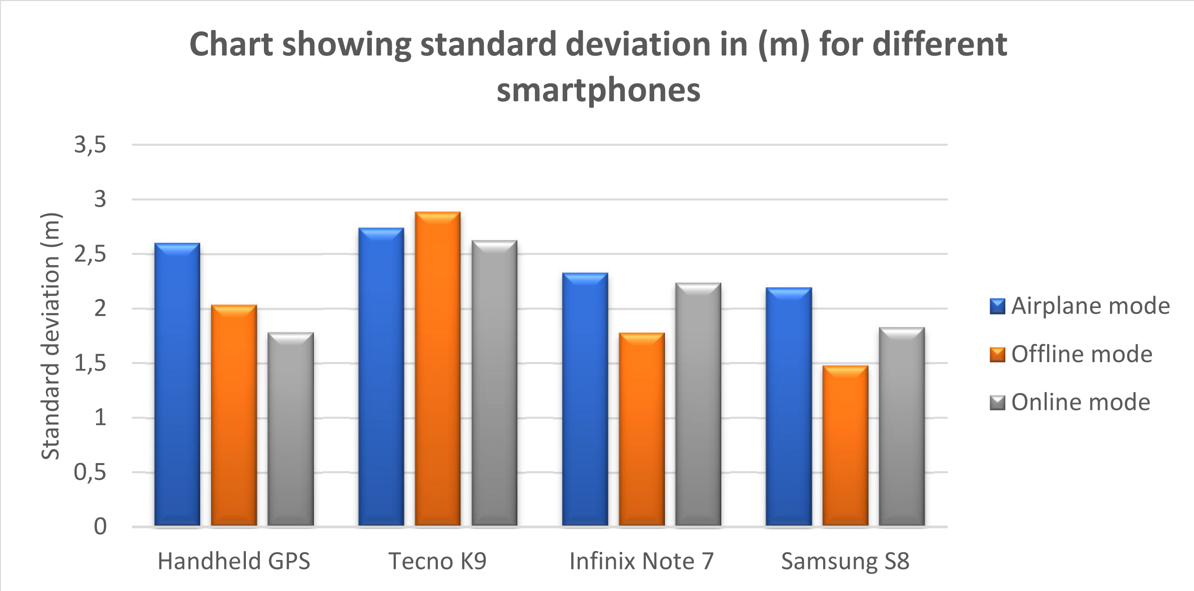

Figure 4. Comparison of handheld GPS and smartphones horizontal positioning errors in three different modes.

3.1. Statistical Testing

A two-way analysis of variance (ANOVA) was employed to conduct a comprehensive analysis of the mean observed values obtained from the field. The dependent variable was the DGPS value, while the independent variables were the phones (SAMSUNG, INFINIX, and TECNO) in their various modes, along with the handheld GPS observation. Table 5 presents the actual results of the two-way ANOVA, indicating whether either of the two independent variables or their interaction was statistically significant at 95% (0.05 significant level) confidence level. The decision rule is as follows: if the p-value obtained from the analysis is greater than 0.05, it indicates that there is no statistically significant relationship between the smartphones, mode of observations, and the handheld GPS results.

Table 5. Results of ANOVA test for DGPS Values with smartphones, modes of observations, and handheld. GPS

Source	Type III sum of squares	Degree of freedom	Mean square	F	P-value
Corrected model	50.054	8	6.257	1.210	0.298
Intercept	10537.029	1	10537.029	2037.871	0.000
Smartphones	36.476	2	18.238	3.527	0.032
Mode of observations	1.080	2	0.540	0.104	0.901
Handheld GPS	8.392	2	4.196	0.896	0.416
Smartphones * Mode of observations * Handheld GPS	12.498	4	3.124	0.604	0.660
Error	651.496	126	5.171		
Total	11238.579	135			
Corrected Total	701.550	134			

Based on the result in Table 5, no statistically significant interaction was observed at the p = 0.660 level among Phone, Mode, and Handheld. Furthermore, a statistically significant difference in the mean DGPS was found between the observed values of Samsung S8, Tekno K9, and Infinix Note 7 (p-value = 0.032). However, there was no statistically significant difference between mean observations in Airplane mode, offline mode, or online mode (p-value = 0.901). This indicates that there was no noticeable difference between data observed in different modes using the smartphones and can be regarded as the same once it is observed in an opened sky with no obstructions. Since the analysis in Table 5 demonstrates a statistically significant difference in the mean observations between the usage of Samsung S8, Tekno K9, and Infinix Note 7 (p-value = 0.032), a post hoc test was conducted to determine which interaction contributed to this difference.

3.2. Tukey Post-hoc Test

The Tukey post-hoc test was conducted to perform multiple comparisons between the observations and validate the analyses presented in Table 5. For this test, a norm was calculated using the formula $D = \sqrt{\Delta x^2 + \Delta y^2}$ and the D represents distance.

Table 6. Results of Tukey post-hoc test.

(I) Smartphone	(J) Smartphone	Mean difference (I-J)	P-value	95% Confidence interval	
				Lower bound	Upper bound
Samsung	Tekno	0.572	0.459	-0.565	1.709
	Infinix	-0.699	0.315	-1.836	0.438
Tekno	Samsung	-0.572	0.459	-1.709	0.565
	Infinix	-1.271	0.024	-2.408	-0.134
Infinix	Samsung	0.699	0.315	-0.438	1.836
	Tekno	1.271	0.024	0.134	2.408

The results of the Tukey post-hoc test, with distance as the dependent variable, aimed to determine which interactions among the independent variables (i.e., smartphone observations) contributed to the mean differences shown in Table 6. The analysis revealed a significant interaction at the 0.05 significance level between the Tekno and Infinix smartphones, with a P-value of 0.024. This indicates that the difference in mean observations is mainly influenced by the interaction between observations taken on the Tekno K9 and Infinix Note 7 smartphones. Furthermore, Table 6 also demonstrates that there were no significant interactions between the Samsung and Tekno smartphones (P-value = 0.459) and between the Samsung and Infinix smartphones (P-value = 0.315) at the 0.05 significance level, respectively.

3.3. Hypothesis Testing: Handheld GPS Vs. Smartphone Mean Positioning Difference

ANOVA test was again conducted to assess whether the observed data from the smartphones can serve the same purpose as the survey-grade handheld GPS based on the distance. The hypothesis is stated below.

H_0 = The mean distance observed with handheld GPS is equal to mean distance observed with smartphones GPS.

H_1 = The mean distance observed with handheld GPS is not equal to mean distance observed with smartphones GPS.

The decision rule is that, if the estimated p-value is greater than 0.05 at 95% confidence level, we accept the null Hypothesis, H_0 and reject the alternative Hypothesis, H_1.

Table 7. ANOVA test of handheld GPS vs smartphone mean positioning difference.

	Sum of squares	Degree of freedom	Mean square	F	P-value
Between Groups	8.392	2	4.196	0.896	0.416
Within Groups	196.719	42	4.684		
Total	205.111	44			

It can be seen from Table 7 that the estimated P-value is 0.416, which is greater than the significance level of 0.05. Therefore, based on the ANOVA test at the 0.05 significance level, we fail to reject the null Hypothesis, H_0 and conclude that there is no significant difference in the mean distance observed between the handheld GPS receiver and smartphones GNSS.

4. CONCLUSION

The statistical analysis of the field observations revealed that the error of smartphone observations, when compared to DGPS, ranged from 2-15 m, and compared to handheld GPS, it ranged from 0.2-10 m. Additionally, observations made in different modes showed no significant differences, indicating consistent performance regardless of the mode. The plotting of stations demonstrated the close alignment of smartphone observations around the handheld GPS plotted points, particularly towards the south-east region of the DGPS point. Furthermore, the ANOVA test conducted shows that there is no significant difference between the handheld GPS and smartphone GPS distance at 95% confidence level. While smartphone GPS accuracy has shown improvement and holds promise for future advancements with the adoption of different GNSS technologies, it is currently not precise enough for professional survey activities. However, it can be considered suitable for reconnaissance and navigation purposes in surveying. Further research and advancements in smartphone GPS technology are needed to achieve higher accuracy levels and ensure their potential integration into professional surveying applications.

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