Comparative Analysis of Smartphones and Survey-Grade GNSS Receivers for Parcel Boundary Determination

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Abstract
This paper advances the existing body of knowledge on the suitability of the accuracy derivable from the use of smartphones for cadastral mapping. Zenvus App software was installed on two smartphones of a different make. A set of dual-frequency GPS Promark 3 receivers and two different smartphones of different makes were used for data acquisition. Observations were carried out at the boundaries of ten parcels of land, comprising 46 boundary points. The coordinates of these points were obtained using Differential Global Positioning System (DGPS) observation in static mode and two Android smartphones (the Samsung A70 and the Tecno Spark 3 Pro). Mean score, root mean square error, and one-way analysis of variance were used to show significant differences in the equipment used. Overall, both the accuracy (mean) and precision (RMSE) were lower than those obtained by Differential GPS. A one-way analysis of variance (ANOVA) was calculated on the values of both X and Y. For X, the analysis was not significant; F (1, 45) = 0.88, p = 0.419 and for Y, the analysis was also not significant; F (1, 45) = 0.97, p = 0.383. The total RMSE shows that the coordinates of points as obtained by the Samsung smartphone (3.368) were more precise than those obtained by Tecno (4.041). However, the two smartphones (Tecno and Samsung) were less accurate than differential GPS. This implies that there is a 95% chance that the errors in the estimates are less than 6.993m (for Tecno) and 5.848m (for Samsung), respectively. The variation in the observations obtainable with smartphones affects both linear and polygon estimates. The study concluded that the magnitude of these errors is significant in cadastral survey practices and hence not suitable for use. It is recommended that further studies be carried out on the use of the Zenvus app on centimeter grade smartphones; probably this could yield a better result suitable for cadastral mapping.

Keywords: Demarcation, Accuracy, Zenvus, GPS

I. INTRODUCTION
Parcel demarcation is a worldwide phenomenon necessitated by the numerous activities (transportation, agriculture, etc) taking place on land. Due to the fixed nature of land and increase in population, the world is faced with the choice of managing the limited and fixed land resources for sustainable development. Arising from this need, surveyors, geomaticians, and other stakeholders are saddled with the responsibility of demarcating the limited land resources to guarantee the security of ownership.

The need for real-time information on land parcel is increasing. The daily need for cadastral maps as a basis for decision making cannot be overemphasized. The map as a scientific and sometimes legal document needs to be reliable, accurately and precisely done in order to facilitate well-informed decisions. Various approaches employed at demarcating parcels in the past can no longer meet the realities of today where decisions are to be taken in real-time with the highest precision; hence the era of smartphones and drones.

Smartphones are personal devices equipped with different sensors, connected to the Internet, and, most importantly, charged by their users [1]. The use of diverse Apps on smartphones is gaining recognition in the mapping industry and is gradually changing the tradition in cadastral mapping especially the legal aspect. Some of the known apps include My GPS coordinate, Compass360 PRO, and Map Measure. There are also indoor positioning apps installed on smartphones that detect various walking patterns [2]. The use of a smartphone for mapping activities has made surveying easier and time-efficient [1].

Different smartphones exhibit different capabilities in position capturing due to sensors available on the devices such
as small inertial measurements units (IMUs), proximity sensors, barometer, and GPS/GNSS [3]. However, the capabilities and limitations of these various smartphones are not adequately documented. In addition, these studies have focused on the use of smartphones with different applications (Apps) installed on them.

Recently, an intelligent solution, known as Zenvus Boundary Mobile App, for demarcating properties was developed by Ekekwe [4]. Zenvus Boundary is a web App capable of being installed on an android tablet or phone by downloading and installing it from Google play. The App, which requires Internet access, supports two accounts: the Landowner and Enterprise accounts. The former is an individual account that allows the owner to print or download their reports themselves from the Zenvus portal; the landowners do not need a code during data transfer while the latter, which is a collection of accounts, requires a unique code from Zenvus Admin for the purpose of data transfer into Zenvus web portal after mapping [5]. However, there are little known studies on the novel Zenvus Boundary App to determine its ability for classical surveying purposes. Though there is little statistical evidence on the appropriateness of the Zenvus App for parcel demarcation [6]. However, these specifications were ignored in Zenvus App developed by Ekekwe, which caused a conflict between the App developer and the Surveying professionals.

It is thus necessary that an investigation be conducted into the suitability and adequacy of this App for parcel boundary determination. This paper addressed this issue to determine the benefits or dis-benefits of using this App in Nigeria. In achieving this aim, this paper focused on the use of this App installed on two different smartphones and compares their results with a widely acceptable standard of using GNSS receivers on Promark 3.

II. LITERATURE REVIEW

Precise point positioning is core to boundary determination [7]. This can be achieved through diverse approaches such as traversing, trilateration, triangulation, resection, remote sensing, and photogrammetry among others, and also using diverse equipment/devices such as a theodolite, total station, aircraft, laser scanner, satellite scanner, Global Positioning System, drone and smartphone, etc. Due to the availability of Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) coupled with the urgent and high demand for position data, the business of position determination could no longer be left in the hands of trained experts. For instance, rural

![Diagram](image_url)

Fig. 1. Data Quality elements and sub elements

Source: (European Standard ISO 19113, 2002)
and urban areas are mapped using handheld GPS and innovative techniques [8]. Smartphone apps are also developed to support the need for geographic data.

Smartphones are spatially adapted devices embedded with GNSS which makes them a VGI oriented device and serve as tool to facilitate collection of geometric data which can thereafter be uploaded on spatial database. As concept of VGI and the necessity to build VGI application in land surveying and planning in developing countries is rapidly increasing, land surveyors adopt VGI techniques to various tasks applicable to generating new maps like land cover and transportation in rapidly urbanized areas [9].

Smartphone positioning, being a recent development, has greatly enhanced navigation business and mobile location-based services [10]. In recent times, there is growing awareness in the use of smartphones for location-based solutions and there is constant development of position-based applications compatible with a smartphone. In line with this development, researchers continue to thrive in this direction as well. Smartphone has found applications in several fields such as civil engineering [1], aviation [11] water quality analysis [12], indoor positioning [2], [10], [13], [14], [15] and outdoor positioning [16], [17], [18], [19] (usually coordinates) to the true position.

Accuracy is the closeness of results of observations to the true values or values accepted as being true. This implies that observations of most spatial phenomena are usually only considered to be estimates of the true value. The difference between observed and true (or accepted as being true) values indicates the accuracy of the observations.

The fundamental issue with respect to data is accuracy. Positional accuracy is analysed in absolute and relative terms. Absolute accuracy concerns the accuracy of data elements with respect to a coordinate scheme, e.g. Universal Traverse Mercator (UTM). Relative accuracy concerns the positioning of map features relative to one another. Often relative accuracy is of greater concern than absolute accuracy.

Various studies have been carried out in the past in order to check data quality. GPS is often preferred over its alternatives such as GSM/WiFi based positioning systems because it is known to be more accurate [20]. Yiolo et al [21] carried out a data quality check of control points established in Osun State, Nigeria. The purpose was to ensure completeness and consistency of data before various users make use of it. The coordinates of points earlier determined independently using dual-frequency GPS were checked using continuously operating reference stations (CORS). It was discovered that control extension carried out with differential GPS was good and safe to use for mapping purposes. Oluwadare [22] studied the use of handheld GPS in conjunction with CORS data for position determination and noted that the accuracy obtainable will not pose any serious threat to boundary conflict in farmland but possible of creating conflict in urban areas where there is high competition for limited spaces. Oluwadare and Oguntade [23] studied position determination using smartphones and GPS and discovered that the Application is not suitable for cadastral mapping needed for title registration. The paper recommended Zenvus Boundary Application for navigation and mapping of boundaries not intended for cadastral purposes. Oluwadare and Oguntade [23] did not give an adequate statistical analysis of variation that existed between the smartphones and GPS. In addition, the methodology was not strictly based on a designed parcel fabric.

Increasing participation of both experts and non-experts in position data acquisition through crowdsourcing, volunteered geographic information (VGI) has cost and time benefits [9], [24]. However, the issue of accurate positioning is mostly compromised. Laarakker and de Vries [16] explored potential perspectives and weaknesses of crowdsourcing in Cadastre. Constant efforts are being made by experts at probing the integrity of positions derived from the use of smartphones and google maps. Numerous attempts have been made at solving problems of inaccurate definition of positions emanating from the use of smartphones, OpenStreetMap and google map [3], [8], [18], [19], [25], [26].

Navratil and Frank, De Vries et al and Basiouka et al investigated the term Neocadastres in an effort to explore the involvement of Volunteered Geographic Information (VGI) within the traditional methods of Cadastre [19], [27], [28]. Basiouka et al [19] attempted the possibility of using OpenStreetMap (OSM) for official mapping projects and weighed the contributions of experts and amateurs in such projects while El-Ashmawy [29] tested the positional accuracy of OpenStreetMap data for mapping applications. Basiouka et al [19] revealed that a significant difference occur in the accuracy of OSM and the commercial software. The results of El-Ashmawy’s research show that OpenStreetMap data has positional accuracy of 1.57 m which is suitable for generating planimetric maps of scale 1:5000 or smaller. The obtained results embolden the use of OpenStreetMap maps for general preliminary planning where larger areas are covered but only moderate accuracy is needed. It then suggests that OpenStreetMap data are not reliable and acceptable for cadastral survey. In Nigeria, the cadastral regulations set a linear accuracy at 1/5000. The implication of this is that maximum error of 1metre is expected over a total distance of 5000 metres.

The American Society for Photogrammetry and Remote Sensing (ASPRS) highlights the accuracy requirement for a well-defined point (see Table 1). The table shows that small scale map to be produced in 1/20,000 can accommodate Root Mean Square Error of 5metres. Large scale cadastral map can only accommodate RMSE that falls within the range of 0.0125 – 1.25. RMSE greater or outside this range will not be suitable for cadastral survey purpose.

Basiouka et al [19] proposed a semi-hybrid approach which encourages a synergy among experts, volunteers and NGOs participation in and application of Geographic Information. This will provide a wider participation in land tenure and registration [8].

Using Greece example, Basiouka et al [19] proposed online cadastral application via the web or through online processing using installed applications in smartphones. In their methodology, they compared smartphones with the Total station survey. Smartphone observation was carried out at the same location twice at 30 minutes interval to allow independent
satellite constellation tracking. The average error between coordinates obtained through conventional Total Station and Smartphone ranges from 1.7m to 8.5m. Their research concluded that GNSS measurements from the mobile phone are very inaccurate and inappropriate for cadastral surveying purposes. They advised that surveyor must not use any equipment without first determining its accuracy.

TABLE I. ASPRS PLANIMETRIC COORDINATE ACCURACY REQUIREMENT FOR WELL-DEFINED POINTS (CLASS I MAPS)

| Planimetric (X or y) Accuracy (limiting RMSE in Meters) | Typical Map Scale |
|---------------------------------------------------------|-------------------|
| 0.0125                                                  | 1:50              |
| 0.025                                                  | 1:100             |
| 0.050                                                  | 1:200             |
| 0.125                                                  | 1:500             |
| 0.25                                                   | 1:1,000           |
| 0.50                                                   | 1:2,000           |
| 1.00                                                   | 1:4,000           |
| 1.25                                                   | 1:5,000           |
| 2.50                                                   | 1:10,000          |
| 5.00                                                   | 1:20,000          |

Looking at equipment design as a contributory factor to the issue of accuracy, Pesyna et al [18] hinted that under good multipath conditions, 2-to 3-meter accurate positioning is typical while 10 metres or worse is obtainable in an adverse multipath condition. They however demonstrated the possibility of a centimeter accuracy positioning with a smartphone-quality Global Navigation Satellite System (GNSS) antenna. This is possible where additional effort is made by the manufacturers at equipping phones with such quality grade antenna. Common antenna found in most smartphones is the low-quality consumer-grade type. Where antenna type is not expressly stated as a specification in the adoption of an app, variation is bound to occur and if different smartphones with different specifications are used to acquire data into the same database or web portal, map produced from such arrangement will be misleading and trigger more confusion for the users.

Dabove [3] Compared iPhone, an older generation phone which is able to track GPS satellites only, and modern Galaxy S5 Samsung which is able to track both GPS and GLONASS satellites. The two phones exhibit different features in terms of their designs and this reflected in the differences in their position determination outputs. Pesyna et al in [18], [25], using signals obtained with smartphones antenna, pointed out that processing of carrier-phase differential GNSS (CDGNSS) is significantly affected by multipath-induced phase errors due to the antenna’s poor multipath suppression ability. Dabove [3] also affirmed that the accuracy of smartphone positioning depends mainly on the environment, in terms of obstacles, satellite visibility, and multipath. Counselman et al [30] and Mohiuddin et al [31] suggested the technique of replacing standard code-phase positioning with carrier-phase differential GNSS in order to suppress the multipath error. Dabove [3] attempted to reduce the multipath error by carrying out double observation of a series of points. Beyond this approach, since antennae design determines resistance to multipath error, Geodetic- and survey-grade GNSS antennas are designed to have a highly stable phase center and a
gain pattern that strongly attenuates multipath-prone low-altitude signals [26].

The first dual-frequency Global Navigation Satellite System (GNSS) Smartphone (Xiaomi Mi 8 Android), equipped with a Broadcom BCM47755 chip, was launched in 2018 by Xiaomi. The smartphone is capable of receiving signals from GPS, Galileo, Beidou, and GLONASS (Global Navigation Satellite System) satellites [31]. Robustelli et al [32] determined position using multi-constellation, dual-frequency pseudorange, and carrier phase raw data collected from Xiaomi Mi 8 Android smartphone. Furthermore, the availability of dual frequency raw data allows the multipath performance of the device to be assessed. The smartphone’s performance was conducted under two different multipath conditions and compared with that of a geodetic receiver. Smartphone measurements showed a lower carrier-to-noise density C/No and higher multipath compared with those of the geodetic receiver.

Availability of raw carrier and code phase observables from smartphone GNSS allows it to be written to a file in standard RINEX format for CDGNSS processing [26]. In addition, Rinex On app produced in 2018, provides directly both observation and navigation files in RINEX 3.0.3 format and this made the smartphone data to be processed further using post-processing GNSS software [32].

Previous research has linked errors obtainable from smartphones with multipath, antenna type, and sensors. This study investigates and analyses the significance and variability of the errors in measurements and observations carried out with the selected smartphones. To test if there are significant differences in data output generated using the same application on two different smartphones. What purpose at its best can Zenvus App serve when installed on heterogeneous smartphones? Should the App be adopted for high accurate survey work or any less accurate survey work? How can the use of the mobile smartphon be improved upon if it has to be adopted for survey-grade work? With a focus on specific parcels of land in a layout within the Obafemi Awolowo University Ile-Ife campus, this paper provides answers to this question and extends Oluwadare and Oguntade [23] by testing the statistical significance of the Zenvus App for parcel demarcation.

**III. RESEARCH METHODOLOGY**

Fieldwork was carried out on parcels of land allocated to religious associations at the religious centre of Obafemi Awolowo University (OAU), Ile-Ife. OAU campus is situated in Ife Central Local Government Area (see Fig. 2 and Fig. 3). A set of dual-frequency GPS Promark 3 receivers and two different smartphones (Table II) were used for data acquisition. Coordinates of 46 boundary points were obtained using Differential Global Positioning System (DGPS) observation in static mode. The Zenvus Boundary Application was installed on two android smartphones (Samsung A70 and Tecno Spark 3 Pro). The accuracy of the two phones was compared and the differences were compared with those obtained through DGPS. A reference station was established near the site while observations were carried out in static mode. A minimum of 15 minutes was spent on each point in the course of observing with the DGPS. Zenvus App observes in geographical coordinates and was converted to universal traverse Mercator (UTM Zone 31) projected on Minna Datum.

ArcGIS 10.4 software was used in carrying out the following activities: processing of the downloaded Google Earth imagery of the study area (Obafemi Awolowo University, Ile-Ife), extraction of the shapefile from the digitized map of the study area, plotting of the observed points, performing of spatial queries and production of the final map. Microsoft Office Excel was used to deduce the differences between the baseline points and the Zenvus App points. It was also used to determine the Root Mean Square Error. The field data and the baseline data were used for the assessment of positional accuracy of the equipment used.

One of the most widely used statistics in GIS for positional accuracy determination is the Root Mean Square Error (RMSE) expressed as follows (Kerle, et al, 2004):

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_i - \bar{X})^2}$$

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (Y_i - \bar{Y})^2}$$

$$\text{RMSE}_{\text{Total}} = \sqrt{\text{RMSE}^2 + \text{RMSE}^2}$$

Where

- \( \text{RMSE} \) = Root Mean Square Error
- \( N \) = the number of observations
- \( X_i, Y_i \) = predicted values
- \( \bar{X}, \bar{Y} \) = observed values
- \( \delta x \) =RMSE along x-axis
- \( \delta y \) =RMSE along y-axis
- \( \text{RMSE}_{\text{Total}} \) = Total RMSE

RMSE measures how much error exists between two datasets. RMSE usually compares a predicted value and an observed value. For instance, coordinates obtained through Zenvus Boundary Application (observed values) were compared with Differential GPS coordinates (predicted value).

**TABLE II: DEVICES AND THEIR PRINCIPAL CHARACTERISTICS**

| Name                  | Samsung Galaxy A70 | Tecno Spark 3          |
|-----------------------|---------------------|------------------------|
| Operating System      | Android 9.0 (Pie)   | Android 9.0 (Pie),     |
|                       | Upgradable to       | HIOS 5.0               |
|                       | Android 10.0        |                        |
| CPU                   | Octa-core (2x2.0GHz)| Quad-core 2.0 GHz      |
|                       | Krp 460 Gold        | Cortex A53             |
| GPU                   | Adreno 612          | Power VR GE 8320       |
| Digital Camera Resolution | 32Mpx                | 13Mpx                  |
| A-GPS                 | Yes                 | Yes                    |
| GNSS Constellation    | GPS+GLONASS         | GPS+GLONASS            |
| Inertial Platform     | Yes (Accelerometer, | Yes Accelerometer      |
|                       | gyro proximity,     | No Gyro proximity and  |
|                       | compass)            | Compass                |
| Internal Memory       | 128GB, 6GB RAM      | 32GB, 2GB RAM          |
IV. DATA PRESENTATION AND DISCUSSION OF FINDINGS

The results of observations using three different devices (DGPS, Tecno and Samsung) are presented in Table III. In order to have a more complete analysis from statistical point of view, the most significant statistical parameters are summarized in Table IV. The two smartphones exhibit different capabilities of incurring error behavior as a result of their characteristics (see Table II). In both devices, the accuracy (mean) and precision (RMSE) obtained are lower than those obtained using Differential GPS. Accuracy refers to the closeness to the true value whereas precision refers to the spread/dispersion of the results regardless of whether the solution is near the true solution or not.

The errors quantified by Root Mean Square Error (RMSE) for the x and y coordinates for Tecno and Samsung lie between 2.3 and 2.8 metres. An allowable linear error of closure for a traverse of 5000 metre is 1metre while the expected corresponding angular closure is 410. The total RMSE in Table IV shows that coordinates of points as obtained by the Samsung smartphone (3.368) are more precise than Tecno (4.041). However, the two smartphones (Tecno and Samsung) are less accurate than Differential GPS. According to the national standard for spatial data, accuracy at 95% confidence level is more reliable and significant in cadastral survey practice. These results regardless of whether the solution is near the true solution or not.

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Table IV: Error Analysis in Coordinates and Area Obtained from Diverse Devices

| Data Source | Coordinates of Parcel corners | Area of Parcels |
|-------------|-------------------------------|-----------------|
|             | Mean Error | RMSE | RMSE Total | Mean Error | RMSE | % Error |
| X           | Y           | X    | Y          | M²         | Ha   |         |
| ZEN TECNO   | 8.311       | 8.020| 2.883      | 2.832      | 4.041| 0.001   |
| ZEN SAMSUNG | 5.960       | 5.384| 2.441      | 3.368      | 0.001| 0.032   |

Fig. 4 compares the areas of 10 parcels of land as determined using three different devices. It is observed that the areas of parcels do not follow a specific pattern and there are differences in the area of the parcels as shown in Fig 3 and Fig. 4.

A one-way analysis of variance (ANOVA) was calculated on the values of both X and Y. For X, the analysis was not significant, F(1, 45) = 0.88, p = 0.419 and for Y, the analysis was also not significant, F(1, 45) = 0.97, p = 0.383 (see Table V). The same ANOVA test was also repeated using other approaches: Kruskal-Wallis and Jonckheere-Terpstra as summarized in Table VI. In both cases, the results showed that the values are not statistically significant at a 5% risk level (see Table VI). It is evident from the ANOVA results (Tables V and VI) that the mean of the data captured with the three devices were related but the RMSE as earlier pointed out in Table IV were different. This could be as a result of disparities in the characteristics of the smartphones as shown in Table II.
V. CONCLUDING REMARKS

This research investigates the reliability of Zenvus App installed on smartphones for cadastral survey purpose using the religious centre layout of Obafemi Awolowo University Ile Ife as a case study. The positional accuracy of smartphones for cadastral mapping was tested using Root Mean Square Error (RMSE) and other statistical comparative approaches. The position determined with DGPS was used as the baseline data and basis for comparison.

The variances in the data obtained on the two different smartphones, though installed with the same Zenvus Boundary App, were attributed to different sensor abilities of the smartphones. The Zenvus Boundary App requires the user to place the device on safe, stable and accessible areas and there will always be a variation in the coordinates obtained during observation. The accuracy of data acquired with smartphone also depends on the signal strength of the in-built antennae of the device; and its ability to track satellites. In addition, the study revealed that the use of the Zenvus Boundary App on smartphones for area determination of a large expanse of land is not advisable. It gives an inaccurate estimate of the actual size of land. This can result in a serious and undue gain or loss in land transactions.

Though, different devices produce different results, users might ignore them due to variations in smartphone sensors. User should adhere to a specific smartphone for data acquisition. A mixture of two different phone for a particular project might result into serious data conflict. Considering the possibility of centimeter accuracy positioning with quality antennae type as proposed by Pesyna et al (2014), it is suggested that further studies be carried out on the use of Zenvus App on centimeter grade smartphones probably this could yield a better result suitable for cadastral mapping.

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TABLE V: ONE-WAY ANOVA BETWEEN THE ZENVUS BOUNDARY APP ON THE TWO ANDROID PHONES AND DGPS

|      | Sum of Squares | F     | Sig.  |
|------|----------------|-------|-------|
| X    | Between Groups | 48690.926 | .875 | .419 |
|      | Within Groups  | 3869026.958 |       |       |
| Total|                | 3917717.884 |       |       |
|      | Between Groups | 1109011.624 | .967 | .383 |
|      | Within Groups  | 79700255.691 |       |       |
| Total|                | 80809267.315 |       |       |

Source: Author’s Field Data Analysis (2020)

TABLE VI: KRUSKAL-WALLIS TEST AND JONCKHEERE-TERPSTRA ANOVA TEST

| Test                   | X     | Y     |
|------------------------|-------|-------|
| Krusai-wallis test      | 0.914 | 0.961 |
| Jonckheere Terpstra Test| 0.940 | 0.776 |

Source: Author’s Field Data Analysis (2020)
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