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Evaluating GPS Station Configuration Using Root Mean Square Error Analysis

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ABSTRACT

The Accuracy of Global Positioning System (GPS) Station Configuration is a key to any scientific research involving GPS data. Many types of random errors or biases affect both GPS pseudo range and carrier phase measurements. These errors may arise from satellite, receiver or due to signal propagation. This research intends to employ Mean Square Error Analysis among other techniques that could be used in the evaluation of GPS Station configuration. The study involves two Continuously Operating Reference (COR) stations, one from Mpape and the Other one from National Space Research and Development (NASRDA), both in Abuja; with none of them as reference station. The study revealed that station-specific factors (geometry, local environment, antenna setup or processing choices) control whether vertical or horizontal errors dominate; therefore station-level diagnostics: Dilution of Precision (DOP) values, multipath indicators, residual time series; should be examined before combining stations or generalizing accuracy estimates.

Keywords: Root Mean Square error, Earth Centred Earth Fixed (ECEF), GPS Station. Root Mean Squared Error

1. INTRODUCTION

The physical setting of a station in a stable, open location and then configuring its position and communication settings through software is what is meant by GPS Station Configuration. However, sometimes errors are bound to occur in the process. Such errors have profound implications. For the accuracy of GPS, and even go as far as limiting the functionality of GPS in its functions or even making it impossible (capt. Gunter schutze Thailand/ Germany published on 26 February 2020). Several types of random errors or biases affect both GPS pseudo range and carrier phase measurements. These errors may arise from satellite, receiver or due to signal propagation.

The satellite-based errors include; ephemeris, satellite clock errors and the selective availability, which was intentionally implemented by the United States (US) department of defence for security purposes. The receiver-based errors include receiver clock errors, multipath errors, receiver noise, and antenna phase centre variations. The errors due to signal propagation include ionospheric and

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tropospheric delay. In order to find solution to these problems, we need to evaluate the accuracy of GPS Station Configuration in the first place so that we can achieve a better precision for the purpose of meaningful research and development. One of the tools used to evaluate the settings is Mean Square Error Analysis. Root Mean Squared Error Analysis is one of the most used measures for assessing the quality of predictions. The Root Mean Squared Error Analysis shows how far predictions fall from measured actual values using Euclidean distance. In this study we do not have existing values, therefore, we are going to evaluate the configuration of each station independently.

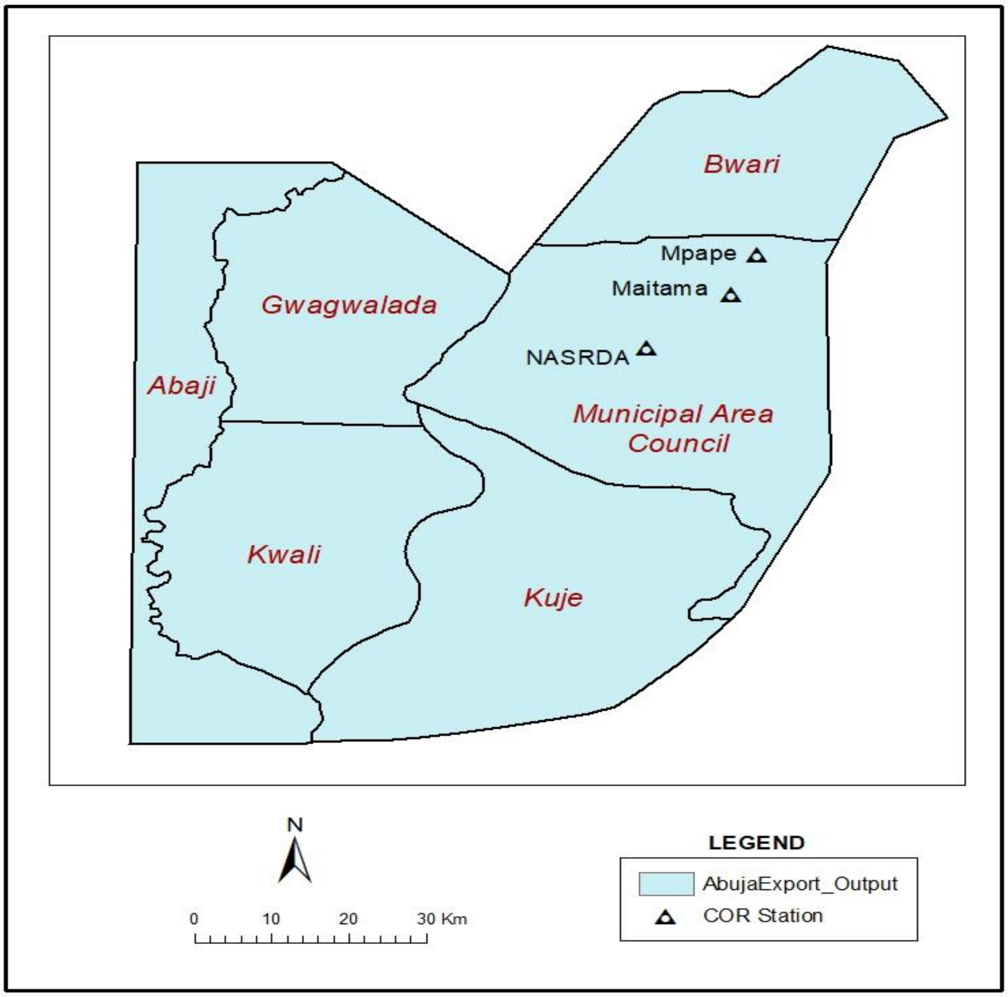

Figure 1: A sketch showing The Federal Capital Territory, Abuja, with the locations of COR Stations

Review of Literature

The RMSE quantifies how dispersed residuals are from, revealing how highly the observed data clusters around the predicted values (Frost, 2023). He further stated that, as the data move closer to the regression line, the model with less error produces more precise predictions.

Hodson (2022) pointed out that Root Mean Square Error is optimal for normal (Gaussian) errors while Mean Absolute Error (MAE) is optimal for Laplacian errors, and when errors deviate from these distributions, other metrics are superior.

Sobby and Hafez (2021), developed a Differential Global Positioning System (DGPS) with the aim of providing enough accuracy of point coordinates measurements, by using minimum number of reference stations. GPS errors have been modelled and tested over the selected study area. The study compared DGPS with code and phase solutions and discussed pros and cons of single and multi-references on GPS observations.

The test results demonstrated that using multi-reference stations can improve the root mean square Error of the coordinate differences by 11% to 33%in the 3D position accuracy, as approved for single reference station scenario. The study presents a novel, systematic evaluation of GPS + Galileo Precise Point positioning (PPP) performance under intense ionospheric scintillation during the rising phase of solar cycle 25 (Maques et al., 2025).

Elhassan (2017), used an RTK technique.to evaluate to horizontal positioning accuracy of Real Time kinematic Global Positioning System (RTK-GPS) available at the surveying engineering program laboratory of the civil engineering department, king Saud university. The results show that. a horizontal positional root mean squared Error of 11mm can be obtained using the Leica SR 530 RTK-GPS.

Figure 2: The COR Station, in Mpape in FCT.

2. METHODOLOGY

2.1. Data Type

The primary source of data for this research is raw data from GPS stations (Fig. 1) installed at NASRDA headquarters located at Lugbe and Mpape, Abuja.

2.1.1. Mpape

Although largely undeveloped, Mpape has lots of potential. Its location near Maitama, the presence of hills, and plans of future development make it attractive for investment. Places of interest include Grange Hill Hotel & Resort, Maitama Hills and Mpape Market (Fig. 2).

2.1.2. NASRDA, Lugbe

Lugbe, Abuja falls under the jurisdiction of the Abuja Municipal Area Council (AMAC). It's a predominantly residential area within AMAC, one of the six area councils that make up the Federal Capital Territory (FCT); (Fig. 3).

Figure 3: The COR Station in NASRDA, Lugbe in Abuja

The datasets from Mpape and NASRDA stations were ppp static, with elevation mask of 10 degrees, and they were processed to get X Y Z coordinates.

2.2. Method of Data Analysis

Root Mean Square was used to analyze the ecef data.

It follows from RMS = $\sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}}$ . . . . (1)

Root Mean Square Error is the statistical measure of the average magnitude of error, which is independent of sign.

It is given by: RMSE = $\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{i-\overline{x}})^2}$ . . . . (2)

In the ecef context, we start by forming the vector ε_i for XYZ coordinates.

$$\begin{bmatrix} x_i - & x_0 \\ y_i - & y_0 \\ z_i - & z_0 \end{bmatrix}$$

Hence the residual vector $\left[{}^{\varepsilon}{}_{i} = \quad {}^{\varepsilon}{}_{x} \quad {}^{\varepsilon}{}_{y} \quad {}^{\varepsilon}{}_{z}\right]$, for each sample. Since we don't have a standard reference station, we would compute the RMSE for each station as a deviation from the mean of each coordinate.

(i) for X coordinate, ${}^{\varepsilon}{}_{x} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{i-}\,x_0)^2}$, Where, x_i is the individual observations from x- coordinate at time t and x_0 is the mean of observations.

(ii) for Y coordinate, ${}^{\varepsilon}{}_{y} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_{i-}\,y_0)^2}$, Where, y_i is the individual observations from y- coordinate at time t and y_0 is the mean of observations.

(iii) for Z coordinate, ${}^{\varepsilon}{}_{z} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(z_{i-}\,z_0)^2}$, Where, z_i is the individual observations from z- coordinate at time t and z_0 is the mean of observations.

for 3D, $\|{}^{\varepsilon}{}_{i} \quad \| \quad = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2}$

where, $(x_i - x_0)^2$, $(y_i - y_0)^2$ and $(z_i - z_0)^2$ are the squares of deviations (errors) from the x, y and z coordinates.

Also, for 2D (i.e Horizontal RMSE),

$RMSE_{2D} = \sqrt{RMSE_x + RMSE_y}$, and vertical RMSE is $RMSE_z$

3. RESULTS

3.1. Mpape

Table 1: Showing RMSE for ecef GPS coordinates from Mpape station

Coordinates	Mean Square Total	Root Mean Square Error	Summary(m)	Directions	Contribution to 3D variance
X	0.016463138	0.12830876	0.1231m	East-west Error	4.6%
Y	0.018358789	0.135494609	0.1355m	North-south Error	5.5%
Z	0.263642073	0.513460878	0.5135m	Height Error	89.9%
3D	0.298464	0.546318588	0.5463m	Combined Error	
$RMSE_{2D}$	0.03482193	0.18660635	0.1866m		
RMSE Vertical	0.263642073	0.513460878	0.5135m		

Source: result from Microsoft Excel 365 analysis of ecef GPS data

Interpretation

Table 1 shows root mean square error from data of the MPAPE station for x – coordinate to be 0.12831m, that is, East-West Error with 4.6% contribution to 3D, for y – coordinate as 0.1355m, that is North -South Error with 5.5% contribution to 3D, for z – coordinate as 0.5135m that is, Height Error with 89% contribution to 3D and for 3D as 0.5463m. For horizontal RMSE (i.e 2D), is 0.1866m while the vertical RMSE is the same Z coordinate = 0.5135m.

3.2. NASRDA

Table 2: Showing RMSE ecef GPS coordinates from NASRDA station

Coordinates	Mean Square Total	Root Mean Square Error	Summary(m)	Directions	Contribution to 3D variance
X	0.363118099	0.602592813	0.6026m	East-west Error	67.3%
Y	0.135415192	0.367988033	0.3680m	North-south Error	25.1%
Z	0.040725216	0.201804895	0.2018m	Height Error	7.6%
3D	0.539261	0.73455	0.7346m	Combined Error	
$RMSE_{2D}$	0.49853329	0.70606890	0.7061m		
RMSE Vertical	0.040725216	0.201804895	0.2018m		

Source: result from Microsoft Excel 365 analysis of ecef GPS data

Interpretation

Table 2 shows root mean square error from data of NASRDA station for x – coordinate to be 0.6026m that is, east-West Error with 67.3% contribution to 3D for y – coordinate as 0.3680m that is, North-South Error with 25.1% contribution to 3D for z – coordinate as 0.2018m that is, Height Error with 7.6% contribution to 3D and for 3D as 0.7346m. For horizontal RMSE (i.e 2D), is 0.7061m while the vertical RMSE is the same Z coordinate = 0.2018m.

4. DISCUSSION

The RMSE results for the two ECEF GPS stations reveal markedly different error structures. For station 1 (i.e MPAPE), RMSE for the axes: were X = 0.1231m, Y = 0.1355m and Z = 0.5135m. Therefore, the vertical component dominates the 3D Error (Z contributes ~ 90% of the squared error) of 0.5463m. indicates significantly degraded vertical precision relative to the horizontal precision and suggests causes, such as, poor vertical satellite geometry (high VDOP), antenna height/levelling errors or vertical based multipath.

For the second station (i.e NASRDA), RMSE for the axes were X = 0.6026m, Y = 0.3680m and Z = 0.2018m, producing 2D = 0.7061m and 3D = 0.7346m (consistent with the component values). Here the horizontal X component accounts for the largest share of 3D variance (~ 67%), indicating horizontal positioning issues (e.g, multipath or local obstructions effecting the horizontal plane or differences in processing), taken together; the results demonstrate that station-specific factors (geometry, local environment, antenna setup or processing choices) control whether vertical or horizontal errors dominate; therefore station-level diagnostics (DOP values, multipath indicators, residual time series) should be examined before combining stations or generalizing accuracy estimates.

5. CONCLUSION

Finally, the research indicates the presence of errors within the stations studied. But further studies must be conducted in relation with geometry, local environment, antenna setup, or processing choices in order to have more reliability on the data coming through the stations. Meanwhile, the error may not be greater ones.

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Authors' Contributions:
The Authors contributed to this work in the following ways:
1. Adamu Ibrahim – contributed with the development of the work, data analysis and interpretation.
2. Muhammad Adamu Bojude – contributed with signal processing that is, converting from signals to the actual numeric form.
3. Maidala Abba Mala – guided in the organization of the work.
4. Lungfa Collins Wuyep – assisted in the download of the signals.

Informed consent

Not applicable.

Ethical approval

Ethical guides were followed in accessing the GPS ECEF data used in the study.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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