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DETERMINATION OF OPTIMAL ANTENNA HEIGHT AND MASK ANGLE OF GLOBAL POSITIONING SYSTEM (GPS) RECEIVER FOR POINT POSITIONING

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Abstract

Global Position System (GPS) receivers are capable of surveying measurement with geodetic positioning accuracy. They are designed to be mounted on a tripod usually with a tribrach and set up for observations with assigned mask angle and height of antenna above the survey marks. Assignation of inaccurate mask angle and height of antenna, during observations, is undoubtedly the most prevalent and frequent biases in GPS set up during control surveying which usually leads to less accurate geodetic positioning. Other errors in GPS observations which have been adequately addressed by many researchers are due to ionospheric, stratospheric, tropospheric, and multipath delays among others.

Goal and Objectives

Therefore, in this research, an attempt has been made to reduce the arbitrary assignation of GPS mask angle and antenna angle to the barest minimum in order to optimise the accuracy of GPS geodetic positioning. That is, optimal antenna height and mask angle of GPS antenna were determined for geodetic point positioning to be adopted for all GPS observations. The objectives were the determination of the positional coordinates of survey mark at different GPS antenna heights by varying the height upward at 1cm interval with constant mask angle until the optimum height was achieved and determination of the coordinates of survey mark at different mask angle by varying the mask angle upward at 1^0 interval with the constant optimum height until the optimum mask angle was achieved.

Methodology

The survey mark used was a known point (control point with existing coordinates) within the Federal University of Technology, Akure using Tersus GPS equipment receiver in static mode of observation. Seventy-six (76) coordinate observations were carried out for the determination of optimum antennal height while twenty-three (23) coordinates were observed for the determination of optimum mask angle. The observed field data was post processed using Tersus Geo office processor software and the results obtained were analysed statistically.

Results

The values of antenna heights and mask angles were plotted against their respective level of errors. It was observed that 1.76m is the antenna height with the least error level while 20^0 is the mask angle with the least level of error. Statistical analysis using hypothesis test carried out on the results showed that there is a significant difference in the level of accuracy between the use of 15˚ mask angle as recommended by the manufacturer of the GPS and the of 20˚ mask angle obtained from this research at 95% confidence level. Therefore, it can be concluded that, in a fairly level terrain, 20˚ and 1.76m have proved to be the optimal mask angle and antenna height respectively for all GPS observations during point positioning. Hence, it is recommended that the results obtained in this research should be adopted for GPS observations for better geodetic point positioning.

Key words:

GPS Antenna height, Mask angle, Hypothesis test

1. INTRODUCTION

GPS offers enormous potential for a wide variety of application in the fields of measurement, mapping, engineering and geographic information. Although many such application require only a two-dimensional position, the three-dimensional capability of the GPS has created an important opportunity for efficient, high accuracy height detection, particularly when traditional levelling methods are very time consuming, inefficient and expensive. GPS provides three-dimensional position at no extra cost. However, when compared to horizontal locations only, GPS does not provide the same geometric weakness, but the same height accuracy due to a few observation errors sources that primarily affect the height component. However, high accuracy of height measurement can be obtained provided that appropriate calculation strategies are adopted. There are a number of faults that need to be taken into account when using GPS for any purpose, but special attention is given to determine the height with GPS. This is because when GPS signal starts to pass from a satellite antenna to a receiving antenna, there are several layers (ionosphere, stratosphere and troposphere) with significant signal quality between entering the Earth's atmospheric layers (Pirtt *et al.*, 2018).

The Global Position System (GPS) antenna is the connecting component between the GPS satellite and the GPS receiver. Its function is to transfer the satellite signal propagation to the receiver with minimum interruption (Even-tzur *et. al.,* 2008)

Most GPS receivers capable of geodetic accuracy are designed to be mounted on a tripod, usually with a tribrach and adaptor. However, there is a trend toward bipod or range mounted antennas. An advantage of this device is that they ensure a constant height of the antenna above the station. The mis-measured height of the antenna above the mark is probably the most pervasive and frequent blunder in GNSS surveying. The tape or rod used to measure the height of the antenna is sometimes built into the receiver and sometimes a separate device. It is important that the height of instrument be measured accurately and consistently in both feet and meters, without merely converting from one to the other mathematically (Jan, 2020).

The measurement of the height of the antenna in a GNSS survey is often not made on a plumb line. A tape is frequently stretched from the top of the station monument to some reference mark on the antenna or the receiver itself. Some GNSS team measure and record the height of the antenna to more than one reference mark on the ground plane. These measurements are mathematically corrected to plumb (Jan, 2020).

The position being measured by a Global Position System (GPS) receiver is located at the phase center of the GPS antenna, being that point in space at which the antenna detects the radio signal broadcast from the satellites. The location of the phase center differs from antenna to antenna, but it is located close to the antenna's conducting surface. The distance and direction of the phase center to the mechanical center of the antenna is established by calibration. The distance from the mechanical center of antenna to the antenna's reference point (ARP) is determined by the antenna's mechanical design. The distance from the ARP to the survey marker is related to the size of the device holding the antenna (e.g., a slant distance to the edge of the tripod face or to the antenna's ground plane or the length of a range pole). Thus, the GPS height of instrument (GPS HI) is the sum of these distances (Meyer et al., 2005). GPS antenna height play a very important role when using GPS in getting coordinate of points on the Earth surface, it has to be set in such a height that will be free from any obstruction and also allow the receiver to track many satellites as possible for better positioning.

GPS signal are radio navigation ones and might be impacted by multipath or tree foliage, multipath occurs when GPS signal is reflected from surrounding objects, such as building, bridges, road gantries and other structures. It represents one of the biggest sources of error in GPS measurement. The only method available to end users to mitigate multipath is to change the mask angle through configuration settings of the receiver, if such settings are available (Pinana-Diaz *et al.,* 2011). It is imperative to determine mask angle that will give a better position coordinate of a point on the earth if the configuration to change mask angle is not available on the GPS.

2. STUDY AREA

The study site of the research is located within the Federal University of Technology, Akure. It is located in Akure South Local Government Area, Ondo State, within the following latitude and longitude: 5°07′01″E, 7°18′58″N; 5°06′52″E ,7°18′10″N; 5°09′01″E ,7°17′33″N; 5°07′01″E, 7°18′58″N. The beacon selected as reference point is FUTA/SVG/14/49. FUTA is a relative plain terrain which covers approximately 578 hectares of land having average elevation of about 374m as shown in figure 1. the network of control points used for the research were the existing beacons established within the University.

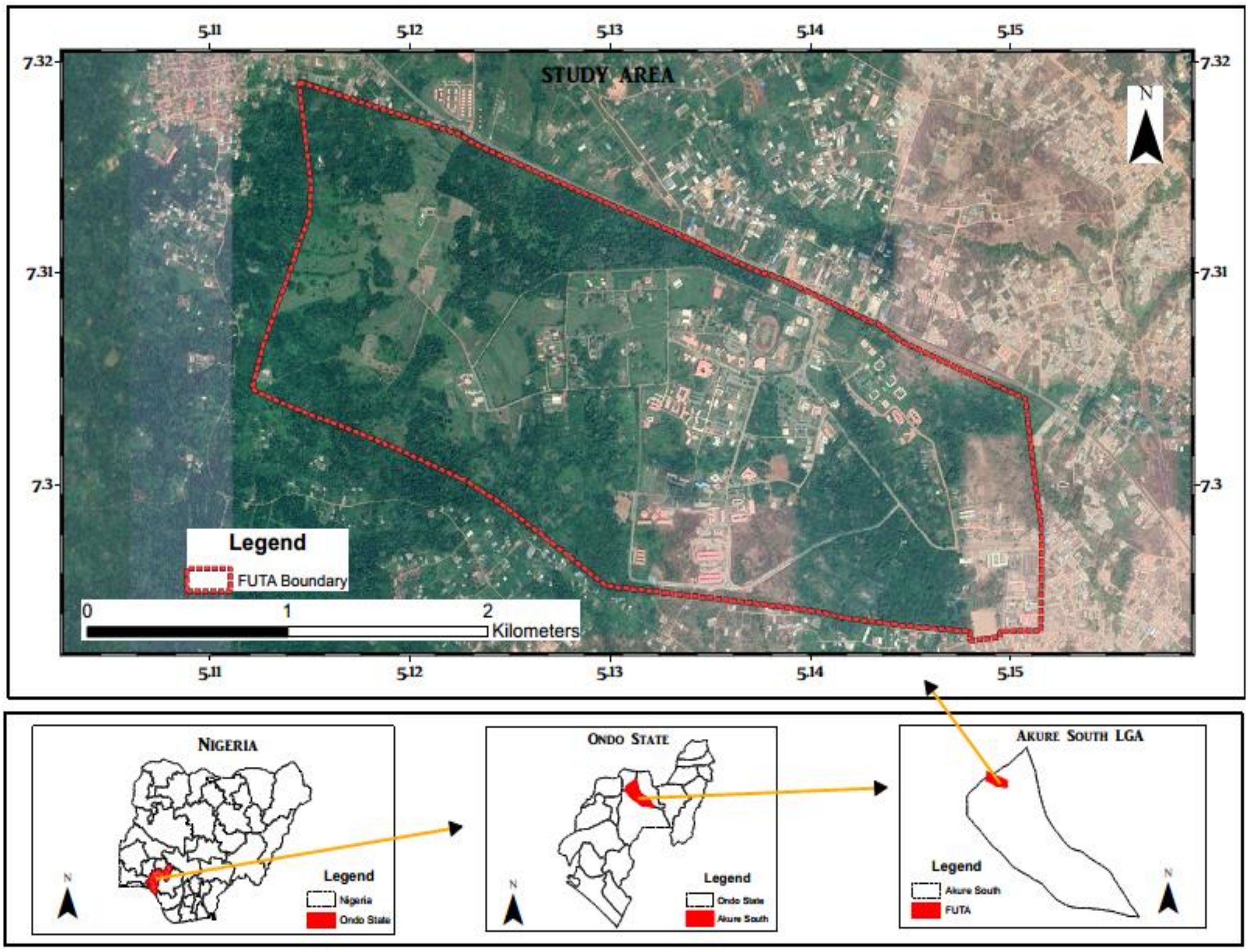

Figure 1: Study Area indicating the locations of the controls used for the study.

3. METHODOLOGY

3.1 Equipment and software

The sensitivity of the aim of this research calls for GNSS equipment that will deliver the required results, hence the choice of the under listed hardware and software.

i. Hardware: Tarsus GNSS receivers' dual frequency and all it accessories
ii. Software: Tersus download, Tersus Geo office, Microsoft package, Micro Excel, and SSPS

3.2 Procedures of observation

The base receiver of the Tersus GNSS was set on the first survey pillar (FUTA /GPS/ 001) while the rover receiver of the same instrument was set up on the second pillar (FUTA/GPS/002). All the adjustments needed for these instruments were performed to get them ready for the observations. Each set of observations on each instrument, either for varying antenna heights or mask angles, covered a period of 30 minutes.

3.2.1 GPS observations for varying antenna heights

The base and rover instruments were set up as discussed above and the antenna as well as data bank were connected to data logger. Also, Bluetooth device was plugged into the data logger I order to control the equipment and to input the station information such as station identification number, antenna height and mask angle supplied by the manufacturer as well as necessary folder for easy retrieval of acquired data. The Bluetooth device, on the data logger, was connected to Huawei y5 phone Bluetooth through Nuwa application. Observations were carried out at the interval of 1cm by increasing the height of the antenna from 1.25m to 2.0m. The acquired data was downloaded using Tersus download software which have the capability of converting the raw data to the processable RINEX data. The steps for the downloading procedures are listed below.

Step 1: The data logger of the GPS was connected to computer and powered by the power bank, then the Tersus download software was lunched and COM 8 on the software was selected.

Step 2: The folder to which the job will saved was selected and click on the window start icon which opened the data logger. The data for that particular day were highlighted using the observation date, download icon was selected on the window interface to display the downloaded observations.

3.2.2 GPS observations for varying Mask Angle

The instruments were set up as discussed above and the antenna as well as data bank were connected to data logger. Also, Bluetooth device was plugged into the data logger I order to control the equipment and to input the station information such as station identification number, newly determined optimum antenna height and initial manufacturer's mask angle as well as necessary folder for easy retrieval of acquired data. The Bluetooth device, on the data logger, was connected to Huawei y5 phone Bluetooth through Nuwa application. Observations were carried out at the interval of 10 by increasing the mask angle from 60 to 280.

To ensure the completeness, precision, accuracy and consistency of the data, all equipment were tested, control points were checked to know their state of intact and also all observations were reference to the same reference system and to ensure the quality of data because of the sensitivity nature of the research to some other surveying projects especially in geodesy the instrument was put to test despite the fact that it was newly acquired by the University.

3.3 Data Quality

Data quality is the degree of data reliability that satisfy the given objective of the research. To ensure the completeness, precision, accuracy and consistency of the data, all instruments were tested, control points were checked to know their state of stability and observations were referenced to the same reference system. (Idowu ,2005) opined that the quality of data used for any experiment can be determined by the validity and reliability of such data. The validity of data is measured by the precision of the set of data while the reliability is a measure of accuracy of the data.

To ensure the quality of data because of the sensitivity nature of the research to some other surveying projects especially in geodesy the instrument was put to test despite the fact that it was newly acquired by the University and also the control points were tested to check for the reliabibilty, the Tersus base receiver was set on FUTA GPS 2 and the rover was on FUTA GPS 1 to acquire data for 30 minutes , thereafter, the rover receiver was moved to GPS 1 to acquired data for another 30 minutes. The data from the observation was downloaded and processed using Tersus Geo office processing software. Comparison was made between the known coordinates of the control points and the processed coordinates to check for difference in these coordinates. It can be satisfactory concluded that the instrument was in good working condition and baseline check also confirm that both the GPS processing software and control points were still in good condition

3.4 Data Processing.

The data acquired for both antenna height and mask angle were post processed using Tersus Geo Office processing software. The coordinate system was predefined Nigeria was selected under which UTM-WGS84- Zone 31N was picked

Projection: (method: Traverse, central meridian: 003:00:00.0000E, false North :0, false East:50000, central Latitude: 000:00:00.0000N) Convert: Bursa- Wolf

4. RESULTS AND DISCUSSION

The results obtained from the study were presented and discussed. These include Tables 1 and 2 showing the extract of results for antenna height and mask angles respectively. Figures 1 and 2 show graphs of level of errors against antenna heights and level of errors against mask angles while Figures 3 and 4 show bar chart of level of errors against heights and level of errors against mask angles

Table 1: Extract of Result of Antenna Height Observations

Antenna	Latitude	Longitude	h(m)	N(m)	E(m)	H(m)	Level error
1.25	07°17'41.56839" N	05°08'07.56827" E	386.574	806785.867	735852.062	361.7055	0.999939391
1.26	07°17'41.56845" N	05°08'07.56837" E	386.579	806785.869	735852.065	361.7104	0.99993939
1.27	07°17'41.56814" N	05°08'07.56833" E	386.579	806785.86	735852.064	361.7103	0.99993939
1.28	07°17'41.56816" N	05°08'07.56829" E	386.577	806785.86	735852.063	361.7086	0.999939391
1.29	07°17'41.56809" N	05°08"07.56837" E	386.579	806785.858	735852.065	361.7107	0.99993939
1.3	07°17'41.56857" N	05°08'07.56821" E	386.588	806785.873	735852.06	36176199	0.999939389

Table 2: Extract of Result of Mask Angle

Mask Angle	Latitude	Longitude	h(m)	N(m)	E(m)	H(m)	Level of error
6	07°17'42"N	05°08'07"E	386.529	806785.874	735852.064	361.760	0.9999393982
7	07°17'42"N	05°08'07"E	386.5283	806785.875	735852.0617	361.794	0.9999393984
8	07°17'42"N	05°08'07"E	386.5321	806785.8728	735852.0575	361.732	0.9999393978
9	07°17'42"N	05°08'07"E	386.527	806785.8725	735852.0582	361.758	0.9999393986
10	07°17'42" N	05°08'07"E	386.5332	806785.8763	735852.0635	361.7643	0.9999393976
11	07°17'42"N	05°08'07"E	386.5168	806785.8665	735852.0493	361.7479	0.9999394002
12	07°17'42"N	05°08'07"E	386.5385	806785.8758	735852.0582	361.7696	0.9999393968

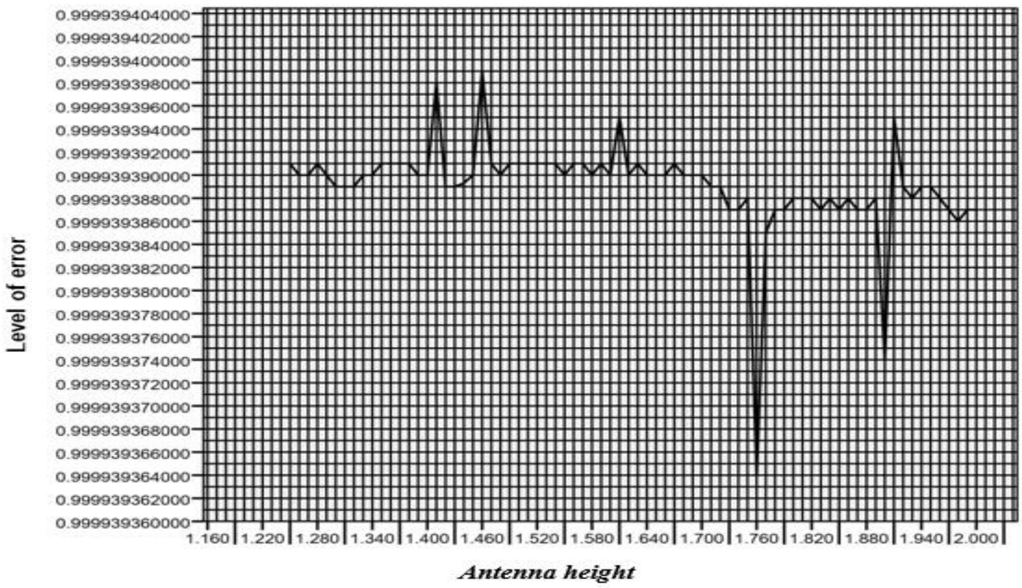

Figure 1: Graph of level of error against height

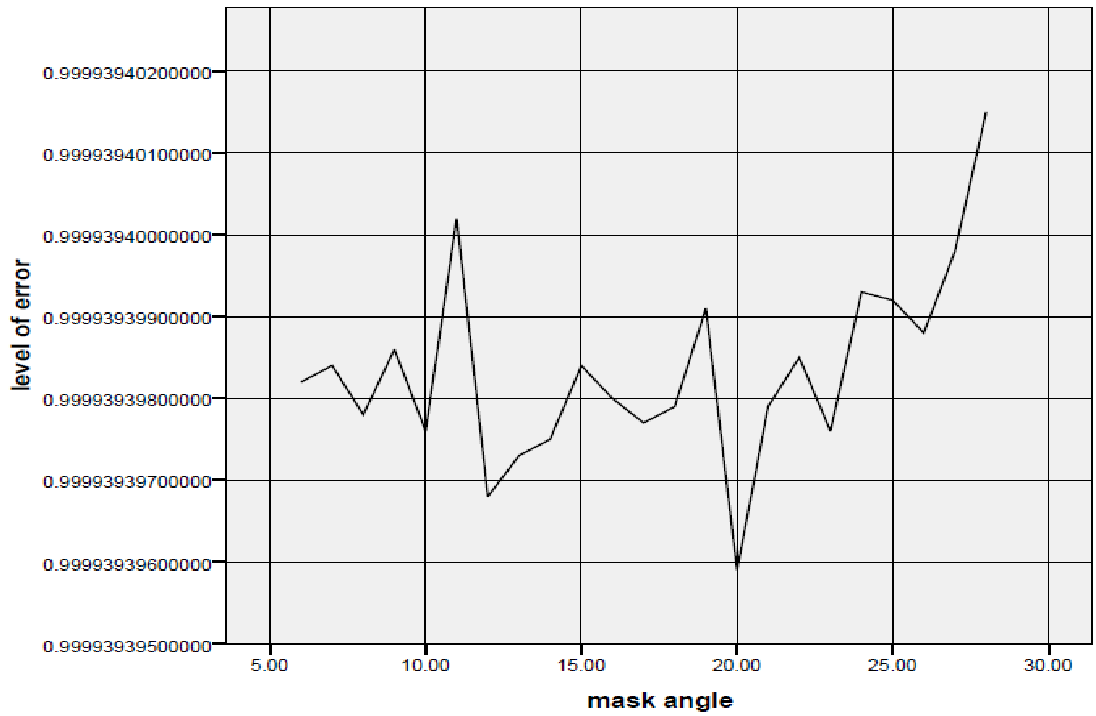

Figure 2: Graph of level of error and mask angle

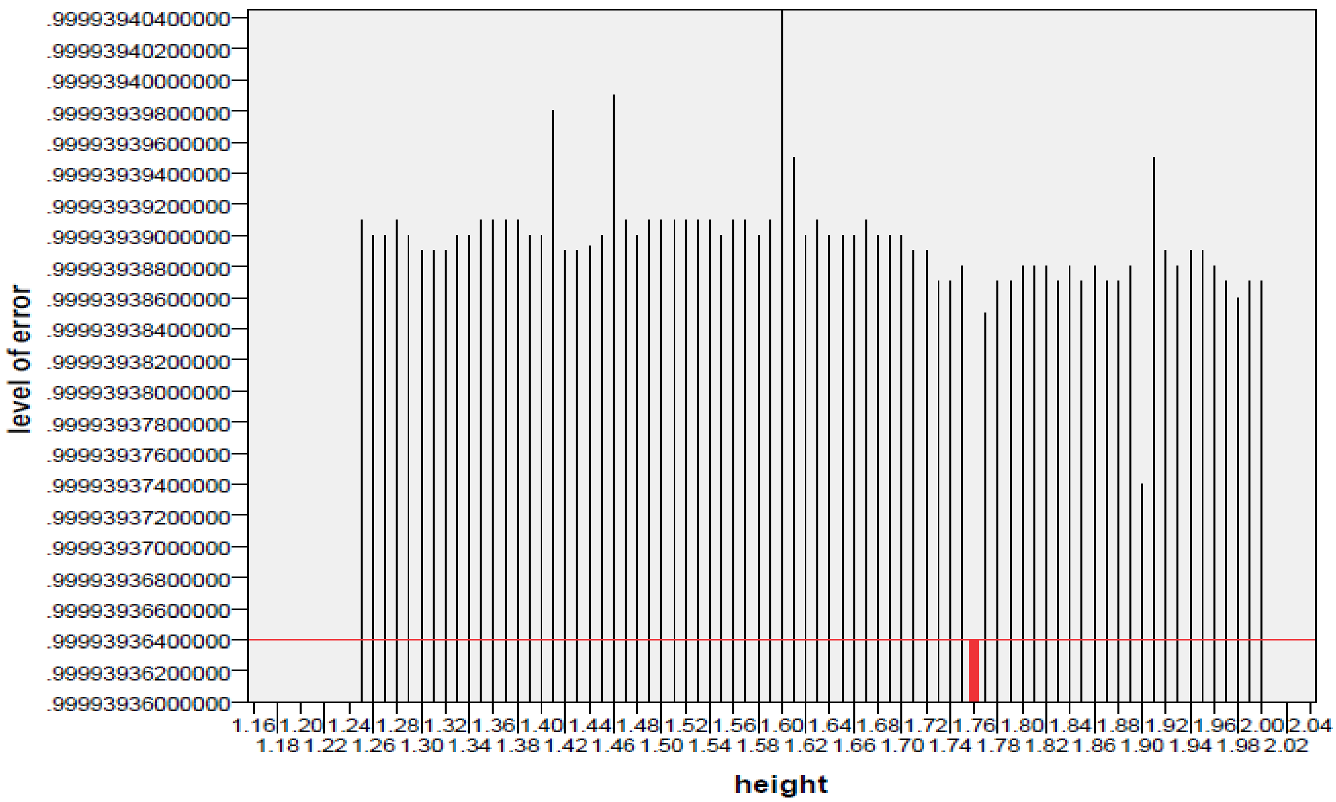

Figure 3: Bar chart of level of error and antenna heights

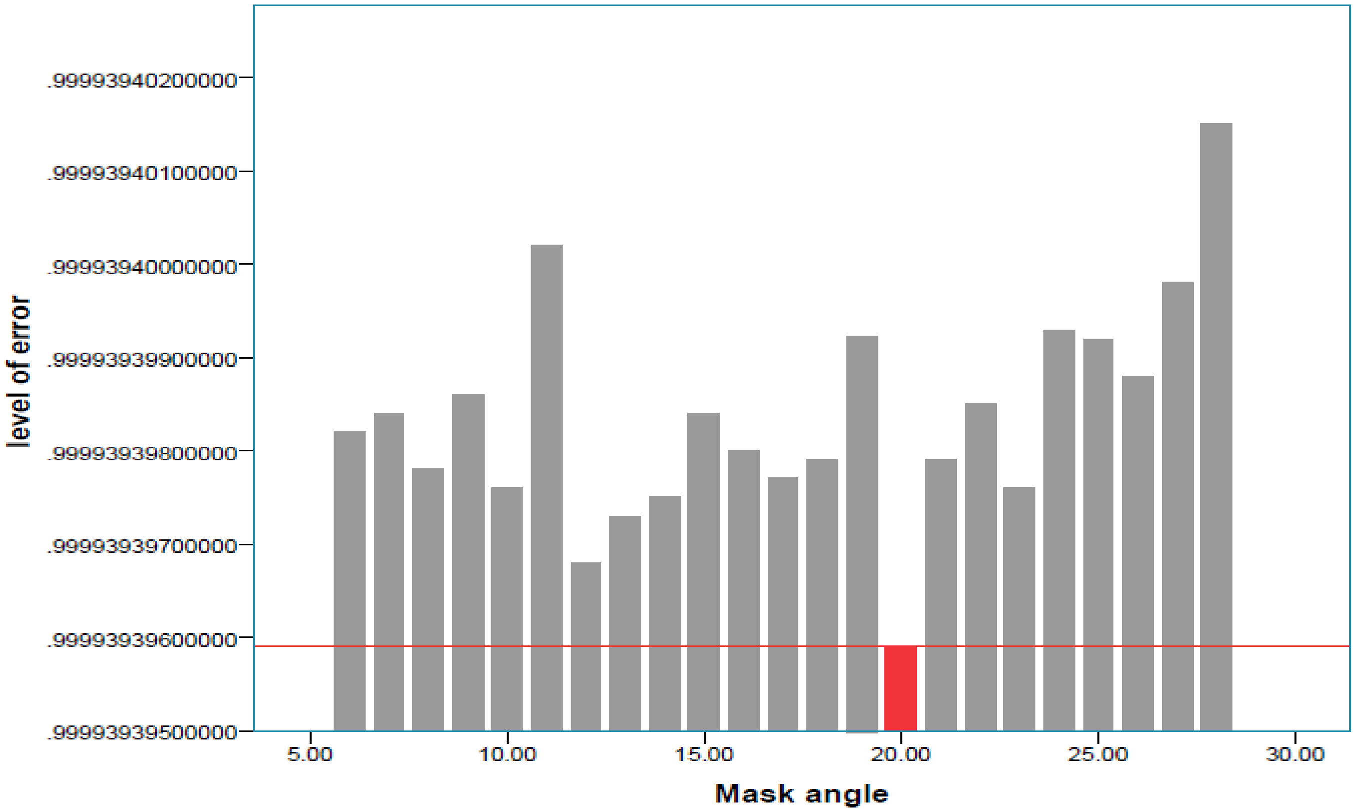

Figure 4: Bar chart of level of error and mask angle

5. ANALYSIS OF THE RESULTS

For the assessment of the relation of the coordinates got for heights and mask angle to the existing coordinates of the point, the root mean square estimator was used Sigrist et al, (1999), RMS error under listed formula was used to calculate precision for both horizontal and elevation coordinates.

Root Mean Square Error

$$RMSE_Y \equiv \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \mu)^2} \quad 1$$

$$RMSE_X \equiv \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu)^2} \quad 2$$

$$RMSE_Z \equiv \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_i - \mu)^2} \quad 3$$

where μ is the known correct value

n is the number of observations of μ

Y_i, X_i, Z_i are one of respective set of the n observations.

Root Mean Square Error for Height

$RMSE_Y$= 0.05119670656554

$RMSE_X$ =0.07974620688884

$RMSE_Z$ = 0.11624739782034

Root Mean Square Error for mask angle

$RMSE_Y$ = 0.04935360

$RMSE_X$ = 0.08289528

$RMSE_Z$ = 0.17269208

Hamid (2017) stated RMSE values greater or equal to 0.5 reflects the poor ability of the model to accurately predict the data. Therefore, it can be deduced that values derived for both optimum antenna height and mask angle are similar as the RMSE are less than <0.5.

Hypothesis testing

F-statistical testing was carried out to determine the performance of degrees of mask angle on point positioning.

(i) The goal is to test whether there is significance difference between the variances in the results obtained for using mask angle of 20^0 proposed in this research and mask angle of 15^0 specified by the manufacturer which is being commonly used for point positioning.

(ii) $H_o: \sigma_1 = \sigma_2$ Null hypothesis to shows that there is no significant difference between the mask angle determined from the research and the mask angle specified by the manufacturer.

$H_1: \sigma_1 > \sigma_2$ Alternate hypothesis is to show that there is significant difference between the variances in the results obtained using the two angles.

(iii) Significance level (α) = 0.05

(iv) Computed F-Statistic is given as:

$F = S_1{}^2 / S_2{}^2 = 986914/8261788 = 1.195$

(v) Table F-Statistic is given as: $F_{1-\sigma}$ (df_1, df_2). That is, $F_{1-\sigma}$ (14,14)

From the statistical table, $F_{.95}$ (14,14) = 2.48

(vi) Since F < $F_{0.95}$ (14,14), the null hypothesis is accepted.

(vii) Therefore, it can be inferred that there is no significant difference between the results obtained if the optimum mask angle derived from the research or the one specified by manufacturer is used.

The hypothesis test carried out implies that either 15^0 or 20^0 mask angle can be used for GPS observations. However, the levels of errors shown in the figures above indicate that the use of 20^0 mask angle led to the results obtained with less error than when 15^0 mask angle was used. Therefore, it can be inferred that where better accuracy of results is required, 20^0 mask angle should be used for GPS positioning. Similarly, from the figures of level of errors against antenna heights, it can be reasonably inferred that 1.76m should be regarded and used as optimum antenna height during GPS positioning.

Furthermore, RSME was used to further analyze the results obtained. Sigrist et al (1999) and Hamid (2017) had stated if the values of RMSE obtained in any research is greater or equal to 0.5, it is a reflection of poor ability of the model to satisfactorily process the acquired data for such research. Therefore, it can be deduced that the results obtained are satisfactory and reflection of good outcome of the research. This is because the values of RMSE are less than 0.5.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

A total of 76 positional coordinates were observed for antennal heights at one-centimeter interval while 23 positional coordinates were observed for mask angle at one-degree interval on point with existing coordinates within the study area using Tersus GPS in static mode. The results obtained for both optimum heights and mask angle revealed that both have Root Mean Square Error (RMSE) that is within the limit of errors for this kind of research. Also, the hypothesis test showed that there is no significant difference between the use of 15^0 mask angle recommended by the manufacturer which is being used by GPS observers and the 20^0 obtained from this research as optimum value. Also, optimum antenna height which is 1.76m has been arrived at, as the appropriate antenna height to be used for GPS observations. Therefore, it can be inferred that, in a fairly level terrain, the use of 20^0 mask angle and 1.76m antenna height for GPS observations will lead to a better GPS point positioning. The optimum height and mask angle determined from this research will be of great help in the field of geodesy and other sciences that have to do with enhanced point positioning.

6.2 Recommendation

The optimum height and mask angle determined from this study should be adopted where GPS observations are required for accurate positioning especially in the field of geodesy and other applied sciences. This study made use of a single instrument and a single point of observation as a reference point in a fairly level terrain. Therefore, further studies should be carried out to encourage development of a model that will involve the use of more than one GPS instruments and different terrain. This work has contributed to the body of knowledge in the fields of geodesy and other applied sciences and this was achieved by its determination of new antenna height and mask angle of GPS receiver for the determination of optimum values of survey station coordinates for better geodetic point positioning.

7. AKNOWLEDGEMENT

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8. FUNDING

No funding

9. AUTHORS' CONTRIBUTIONS

Authors are contributing together in the investigation and analysis of the study

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11. KEY TERMS AND DEFINITIONS

GPS signal: a GPS signal is a radio navigation transmitted by a GPS and received by receivers.

Multipath: multipath occurs when GPS signal is reflected from surrounding objects, such as building, bridges, road gantries and other structures. It represents one of the biggest sources of error in GPS measurement. The only method available to end users to mitigate multipath is to change the mask angle through configuration settings of the receiver.