

Time Optimization for GPS Observation Using GNSS Planning

¹Takana Abubakar,

²Ahmed Babayo &

³Shuaibu Umar

¹Department of Surveying and
Geoinformatics, Modibbo
Adama University of
Technology Yola, Adamawa
State, Nigeria

²Department of Surveying and
Geoinformatics, Federal
Polytechnic Bauchi, Nigeria

Abstract

Surveyors, Engineers, Other Geoscientist, Navigation and civil aviation sectors today heavily relied on Global Positioning System (GPS) for Navigation, projects, and scientific research. However, sometimes Mother Nature's behavior militates against the performance of this modern marvel. This study is an evaluation of the optimum time for GPS observation using predicted satellites visibility and the Dilution Of Precision (DOP) values collected for a period of 12 GPS week at 15 minutes epoch at Modibbo Adama University Yola campus. Statistical analysis reveal that there is highly significant difference in the DOP values observed during the day and night hours. This corresponds to the significant improvement on the satellites visibility during the night hours. The foregoing lead us to conclude that there is a significant improvement in the accuracy of GPS observations during night hours over day hours, and therefore, precise GPS observations is better plan during night hours.

Keywords:

GNSS, Dilution of
Precision DOP,
Satellite visibility,
GPS observation,
GPS planning.

Corresponding Author:
Takana Abubakar

Background to the Study

Over decades, Surveyors, Engineers, and Navigators are trying to answer the questions, where? (Location), when? (Time), how far? (Distance), and how fast? (Navigation). This resulted to using celestial bodies such as Stars and Sun to determine positions on surface of the earth. However, in recent times, technological advancement brought about the paradigm shift from the use of natural celestial bodies to man-made celestial bodies (Satellites) to determine positions on, above, and beneath the surface of the earth. During the 1970s, a new and unique approach to surveying, the global positioning system (GPS), emerged (Khalid et al, 2014). This system, which grew out of the space program, relies upon signals transmitted from satellites for its operation. It has resulted from research and development paid for by the United State Department of Defence DoD to produce a system for global navigation and guidance (Hofmann, 2014). Other countries have developed their own systems; these include GLONASS by Russia, Boudein/COMPASS by China, Galileo of E.U, QZSS by Japan, and IRNSS of India. Thus, the entire scope of satellite systems used in positioning is now referred to as global navigation satellite systems (GNSS). The global positioning system (GPS) is undoubtedly the most important technology that has affected the practices of surveying in the search by the Surveyor to work more efficiently (Moca, 1999). The GNSS systems provide precise timing and positioning information anywhere on the Earth with high reliability and low cost. The systems can be operated day or night, rain or shine, and do not require cleared lines of sight between survey stations. This represents a revolutionary departure from conventional surveying procedures, which rely on observed angles and distances for determining point positions (Khalid et al, 2014).

As accurate as GNSS positioning is, however it is associated to certain setbacks. The reasons for this limited accuracy are different error sources such as satellite orbit, clock errors, ionospheric and tropospheric delays as well as multipath effect, among others (Gunter, 2003). Discovering the techniques that will minimize the effects of the sources of errors in GPS positioning data has attracted researches worldwide. Different techniques and procedures for GPS data acquisitions and processing are now emerging, ranging from Assisted GPS (AGPS) to Differential GPS (DGPS). It is however, pertinent to note that GPS satellites aren't in geosynchronous or geostationary orbits, but are instead in medium earth orbit (MEO) (Tracklog, 2013), hence GPS accuracy varies from time to time. Satellites occasionally go on the fritz, because the constellation is always changing relative to observer's position on the face of the earth, but the biggest issue is the arrangement of the constellation relative to observer's position. The GPS satellite geometry factor is represented by a numerical measure known as "Dilution Of Precision", (DOP), the higher the DOP, the greater the possible error in the positioning accuracy. The concept of dilution of precision (DOP) originated with users of the Loran-C navigation system. The idea of Geometric Dilution of Precision (GDOP) is to state how errors in the measurement will affect the final state estimation. This can be defined as (Dudek & Jenkin, 2000) $GDOP = \frac{\Delta(\text{output location})}{\Delta(\text{measured location})}$

The position of each satellite is changing moment by moment. As the result, these displacements make the spatial resection with different triangles in which differences in forms of resection can lead to error in positioning. Each of these spatial triangles which in shape are in four dimensions of X, Y, Z and time, earn their own points which are called DOP

. DOP is a term used to describe the strength of a satellite configuration on the accuracy of the data collected with GNSS receivers. (Rita, 2003). It is used in satellite traverse and geometrics engineering to specify the additional multiplicative effect of traverse satellite geometry on positional measurement precision. (Amir & Babak, 2016). DOP is the sum of errors in range and the errors in position of the satellites represented as $DOP = E_r + E_p$ computed from the approximate position and satellites position from ephemeris or almanac data (Mark & Micheal, 2012). DOP is often study under different components such as: GDOP, VDOP, TDOP, NDOP, EDOP, PDOP, and HDOP. GDOP is the geometry between the receiver and the set of satellites in view during a location solution by the receiver (Hurn, 1989). While GDOP is used to estimate the total geometry of the satellites to the receiver, PDOP (positional) and HDOP (horizontal) are used more often to estimate DOP for 3D and 2D positions, respectively (Carstensen, 1997). Below is the relationship between the different DOP measures.

Geometric Dilution of Precision (GDOP). The main form of DOP used in absolute GPS positioning is the geometric DOP (GDOP), which is a measure of accuracy in a 3D position and time. The relationship between final positional accuracy, actual range error, and GDOP can be expressed as follows: $\sigma_a = \sigma_R \cdot GDOP$

Where σ_a = final positional accuracy, σ_R = actual range error (UERE)

$$GDOP = \frac{(\sigma_E^2 + \sigma_N^2 + \sigma_u^2 + (c - \sigma_t)^2)^{\frac{1}{2}}}{\sigma_R}$$

Where

σ_E = standard deviation in east value, m

σ_N = standard deviation in north value, m

σ_u = standard deviation in up direction, m

c = speed of light (299,792,458 m/s)

σ_t = standard deviation in time, s

σ_R = overall standard deviation in range, m, usually in the range of 6 m for P-code usage and 12 m for C/A-code usage

Positional Dilution of Precision (PDOP). PDOP is a measure of the accuracy in 3D position, mathematically defined as: $PDOP = \frac{(\sigma_E^2 + \sigma_N^2 + \sigma_u^2)^{\frac{1}{2}}}{\sigma_R}$

PDOP values are generally developed from satellite ephemerides prior to the conducting of a survey. When developed prior to a survey, PDOP can be used to determine the adequacy of a particular survey schedule.

Horizontal Dilution of Precision (HDOP). HDOP is a measurement of the accuracy in 2D horizontal position, mathematically defined as: $HDOP = \frac{(\sigma_E^2 + \sigma_N^2)^{\frac{1}{2}}}{\sigma_R}$

This HDOP statistic is most important in evaluating GPS surveys intended for horizontal control. The HDOP is basically the RMS error determined from the final variance-covariance matrix divided by the standard error of the range measurements. HDOP roughly indicates the effects of satellite range geometry on a resultant position.

Vertical Dilution of Precision (VDOP). VDOP is a measurement of the accuracy in standard deviation in vertical height, mathematically defined as: $VDOP = \frac{\sigma_u}{\sigma_R}$

NDOP (North) describes how a pseudorange affects the horizontal (ie. Latitude) position in the Y direction.

EDOP (East) describes how a pseudorange affects the horizontal (ie. Longitude) position in the X direction.

The geometry of satellites, or lack of it, has obvious implications with regards to GNSS positioning (Odumosu et al, 2015). DOP values are functions of the diagonal elements of the covariance matrices of the adjusted parameters of the observed GNSS signal and are used in the point formulation and determination. The covariance error in positional solution is given as (Lonchay, 2009), (Vodhanel, 2011). $Q_{xx} = \sigma^2 (A^T A)^{-1}$. Therefore $(A^T A)^{-1}$ contain information (DOP) about amplification of the variance on the positional resolution (Kaplan & Hergarly, 2006).

$$(A^T A)^{-1} = \begin{matrix} EDOP^2 & 0 & 0 \\ 0 & NDOP^2 & 0 \\ 0 & 0 & VDOP^2 \end{matrix}$$

The User Equivalent Range Error (URE) which is the root-sum-square of various errors and biases multiply by the DOP values produces the expected precision of the GNSS positioning at the one sigma (1s). To obtain in (2s), we multiply the result by a factor of 2. That is to obtain 95% positional accuracy. PDOP values considered good for positioning are small, such as 3. Values greater than 6 are considered poor. (Mark & Micheal, 2012). According to (Miliken & Zoller, 1980) the best DOP values are <4 but higher DOP values >6 indicates a worse satellite geometry for GNSS positioning. It is pertinent to mention here that study has shown that the GDOP value is affected by the presence of trees in the vicinity of the receiver (Bharat & Roman, 2005).

Broadly speaking, errors in the GPS receiver's positions are due to two factors: the precision with which the distance to each GPS satellite is known, and the geometry of the satellites, i.e. how closely or far apart they're spaced across the sky. User Equivalent Range Errors "URE" is the umbrella term for all of the error sources associated with satellite and receiver clocks, the atmosphere, satellite orbits, and the environmental conditions that lead to multipath errors. Two of the factors in determining the accuracy of your GPS positions measurement are how many GPS satellites are visible from your location, and how evenly distributed over the sky they are. Generally, the more satellites that are visible, and the more evenly they're distributed, the more accurate your position is (Leszek, 2012). To ensure high-precision GNSS positioning, it is recommended that a suitable observation time be selected to obtain highest possible accuracy (El-Rabbany, 2002). According to (Srilatha et al, 2009), best geometry is obtained when one of the satellites is at the zenith and remaining three forms an equilateral triangle and all the four together forms a tetrahedron structure. The larger the volume of the tetrahedron, the better is the value of GDOP. Other researchers relied on observed data at different period of the day and night to predict the best time for GPS

observation. According to (Funtua & Kamalu, 2010) in the study to determine an optimal time for GPS observation in Bauchi, in which they carried out simultaneous observation on five selected points for a period of 14 days observed that, the time of observation has great impact on the accuracy of positioning data. The study also shows that the best time of observation during the day time is evening while afternoon is the worse time for GPS observation. Another study on the comparative analysis of RTK GPS observation during day and night hours shows that, night observations are an excellent source of obtaining precise data therefore, the planning of GPS observation during night hours was recommended (Carlos et al, 2008). This project investigate the preferred time for GPS observation through parametric approach by systematically collecting, collation, and statistically analyzing the predicted satellite orbital data and calculated DOP as well as the periodic satellite visibility using GPS Planning software for a period of 12 GPS week and analyzing the pattern with respect to day and night hours, to complement or supplement the earlier research on the topic. The study was carried out in Modibbo Adama University of Technology Yola. Adamawa state north-eastern Nigeria. Adamawa state is located between Latitudes 7° and 11° , and between Longitude 11° and 14° .; however the result is expected to be valid within 250km radius from the project site as well as any location that has the same DOP characteristics with Yola.

Statement of the Problem

Growing demand for Global-regional geodynamic and deformation measurements of higher accuracy in positioning with a millimeter error base requires an improved method of data acquisition and processing techniques. The known techniques used to minimize the error in GPS positioning such as DGPS, AGPS, and Post-processing are mostly concerned with how precise distance can be measured between the satellites and the receiver, but does a little about the effect of the satellite Geometry in GPS positioning. In most cases Post-processing data indicates that some of the observations didn't meet the accuracy standard. This makes it necessary to redeploy the Survey team to the site and consequently affect the project timing and budget. A Study of Australian Positioning Services (AUSPOS) positional uncertainty at 95% confidence level from post-processing result for a static survey data, shows that despite same instrument was use, same duration on station, and on the same site, but due to time variation only few points passes the required accuracy. This was traced to poor DOP at the time of observations.

Research Questions

This study answered the following research questions

1. Does the time of observation affect the accuracy of GNSS positioning?
2. Is there significant difference in the accuracy of observed GNSS data during day and night hours?
3. In the day time, what is the optimum time for GPS observations?

Scope and Limitation of the Study

This research project investigate the optimum time for GPS observation based on the satellite visibility and the Dilution of Precision DOP collected for 12 GPS weeks.

The study will be limited to the evaluation of best time for GPS observation based on the satellites visibility and the geometry of the satellites in space DOP, as are function of time of observations, taking satellite ranging parameters constant.

Methodology

Monthly broadcast GPS Almanacs were downloaded to GPS planning software observed by Dual frequency GNSS receivers, The GPS planning uses the current GPS Almanac to show the Space Vehicle Code (SVC) numbers and names of the satellites that are to be visible at a given location for a specified period of time, and the computed Dilution of Precision (DOP) at a time. This information is being displayed graphically as well as numerically. These data were extracted in two segments per day (day and night) for a period of 12 GPS week at 15 second epoch, 24 hours of the day. Therefore, 12 sets of day and night DOP values and 12 satellite visibility data were use to accomplish the project.

The data was processed and subjected to statistical analysis and the following results were obtained.

Presentation of Result

Table 1: Mean DOP values for 12GPS weeks

Week	DOP (Day Hours)	DOP (Night Hours)	No of Satellites (Day Hours)	No. of Satellites (Night Hours)
1	2.56	2.43	8.43	8.39
2	2.68	2.38	8.31	8.33
3	2.77	2.41	8.31	8.39
4	2.65	2.44	8.55	8.35
5	2.85	2.46	8.24	8.41
6	2.52	2.45	8.33	8.39
7	2.45	2.56	8.35	8.41
8	2.49	2.46	8.33	8.37
9	2.60	2.51	8.27	8.43
10	2.60	2.40	8.24	8.51
11	2.60	2.48	8.20	8.53
12	2.57	2.49	8.14	8.59
Mean (\bar{x})	2.61	2.40	8.31	8.41
Variance (σ^2)	0.29	0.23	1.68	0.86

Result where presented according to the research questions and Hypotheses were formulated as follows:

Is there a significant difference in the mean DOP values during day and night hours?

Hypothesis B1 Ho: $\mu_1 = \mu_2$ H₁: $\mu_1 \neq \mu_2$ two tailed test

Hypothesis B2 Ho: $\mu_1 = \mu_2$ H₁: $\mu_1 < \mu_2$ One tailed test

Level of significant $\alpha = 0.05$

Since $\mu_1 - \mu_2 = 0$ the standard Z score is expressed as:

$$Z = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} = \frac{0.21}{0.0297} = 7.06$$

Tabulated $Z_{.975} = 1.96$, $Z_{.025} = -1.96$

Since $Z > 1.96$ the null hypothesis is rejected at 95 significant levels. It can therefore be concluded that there is significant difference between the mean DOP values during day and night hours. Testing hypothesis B2 indicates that the DOP values during day hours is greater than that obtained during night hours. This can also be seen from fig.1 below.

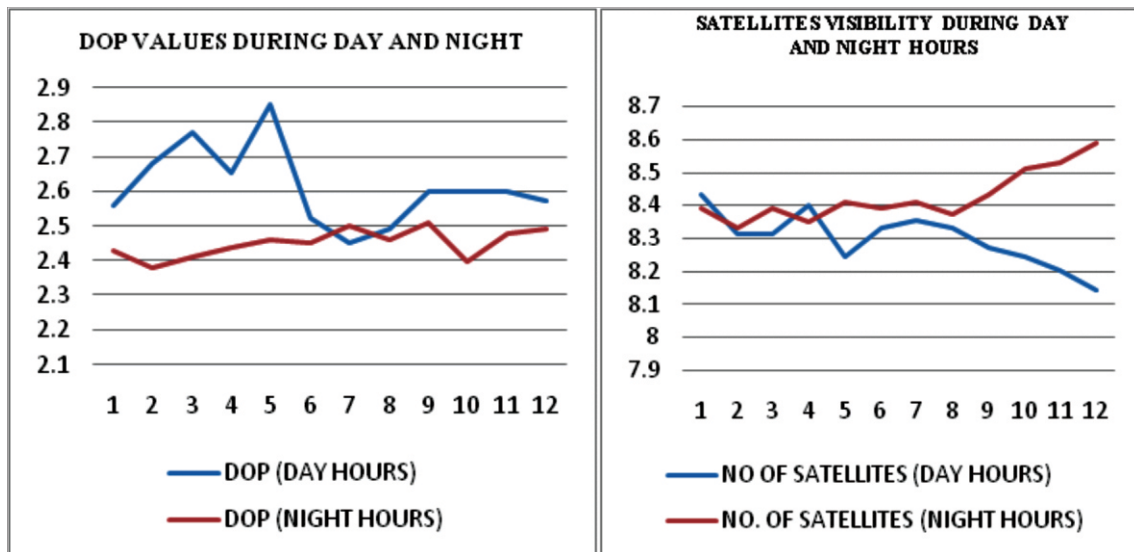


Fig.1 DOP and Satellites visibility during day and night hours

Is there a significant difference in the mean DOP values between morning, afternoon, and evening, during day hours?

This can be done by ANOVA (Analysis of Variance).

Hypothesis B3 Ho: $\mu_1 = \mu_2 = \mu_3$,

H₁: Two or more mean DOP values are not equal. At Level of significant $\alpha = 0.05$.

Week	Preliminary Computation for ANOVA			
	Morning	Afternoon	Evening	
1	2.71	2.51	2.39	
2	2.67	2.66	2.75	
3	2.8	2.62	2.95	
4	2.71	2.62	2.61	
5	3	2.89	2.5	
6	2.49	2.64	2.36	
7	2.34	2.64	2.3	
8	2.62	2.18	2.8	
9	2.39	2.78	2.64	
10	2.55	2.62	2.64	
11	2.54	2.61	2.68	
12	2.58	2.61	2.5	T
Total	31.4	31.38	31.12	93.9
Mean	2.617	2.615	2.593	T²/N
T²/ni	82.163	82.059	80.705	244.923

ANOVA: Parameters for Hypothesis Testing				
Source	Sum of Squares	Degrees of Freedom	Mean Square	Ratio
Between	$BSS = \sum \left[\left(\frac{T_i^2}{n_i} \right) - \frac{T^2}{N} \right]$ = 0.0041	$V_1 = 2$	$S = \frac{BSS}{k-1}$ = 0.0021	$F = \frac{S_1}{S_2}$ = 6.2779
Within	$WSS = \sum \sum x_{ij}^2 - \sum \left(\frac{T_i^2}{n_i} \right)$ = 1.0688	$V_2 = N-K$ = 33	$S = \frac{WSS}{N-k}$ = 0.0324	$F_{1-\alpha}(V_1, V_2)$ = 4.128
Total	$TSS = \sum \sum x_{ij}^2 - \left(\frac{T^2}{N} \right)$ = 1.0729	$N-1$ = 35		

Since $F_{.95} > 4.128$ the null hypothesis is rejected at 95 significant levels. It can therefore be concluded that there is significant difference between one or two mean DOP values of morning, afternoon, and evening hours. Rejecting ANOVA hypothesis leads us to employ a statistics of ORTHOGONAL CONTRAST to know which means are significantly different and which ones are not.

ANOVA Orthogonal contrast.

$H: C_1 = 0, H: C_2 = 0$

Where

$C_1 = \mu_1 - \mu_2 = 0, C_2 = \mu_2 - \mu_3 = 0$ At Level of significant $\alpha = 0.05$

ANOVA Table for Orthogonal Contrast					
Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F-Ratio	Tabulated F-Ratio
$SS_{H:C_1} = 0$	$\frac{(\bar{x}_1 - \bar{x}_2)}{\frac{1}{n_1} + \frac{1}{n_2}} = 0.0024$	2	$S_3^2 = \frac{BSS}{k-1}$ = 0.0021	$F_1 = \frac{SSH:C_1}{S_3}$ = 0.074099	$F_{.95}(V_1, V_2)$ = 4.128
$SS_{H:C_2} = 0$	$\frac{(\bar{x}_2 - \bar{x}_3)}{\frac{1}{n_2} + \frac{1}{n_3}} = 0.4056$	33	$S_3^2 = \frac{WSS}{N-k}$ = 0.0324	$F_1 = \frac{SSH:C_2}{S_3}$ = 12.52281	$F_{.95}(V_1, V_2)$ = 4.128
WSS	1.068833		$S_3^2 = 0.032389$		

Result Summary and Discussion

It is evidence to say that at 95% confidence level the DOP values are higher during the day time than during night hours. Consequently we can say that the accuracy of GPS observations during night hours with (low DOP values) is higher than the day time (high DOP values).

During the day time, it has been established at 95% confidence level that there is no significant difference in the DOP values in the morning and afternoon, but DOP value is lower in the evening. This shows that GPS positioning accuracy improves in the evening than in the morning or afternoon. Therefore generally GPS accuracy improves significantly from evening throughout the night and the accuracy decrease by the daybreak to afternoon time.

Conclusion and Recommendation

The foregoing lead us to conclude that there is a significant improvement in the accuracy of GPS observations during night hours over day hours, and therefore, precise GPS observations is better plan during night hours. When GPS observation is to be carried out during day time, the best time of observation is the evening time. It is therefore recommended that higher precision GNSS positioning such as higher order control establishment, datum establishment, tectonic and structural monitoring as well as higher order geodetic and scientific research positioning should be plan during night ours, and for the short period precise positioning can be carried out in the evening hours.

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