Assessment of Observations with GPS and GPS/GLONASS Satellites in rapid static mode for Precise Point Positioning

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Abstract

The use of Global Navigation Satellite Systems (GNSS) has become a common way of determining planimetric and vertical coordinates used in geodesy, engineering surveying, and related disciplines. The GNSS observation can be achieved using the static baseline, real Time kinematics (RTK) or the continuously operating reference system (CORS). The three are good methods of positioning that gives good and accurate coordinates. The static mode of observation considered by some researchers as the best in determining position of points at a good accuracy is used in this research in addition to its convenience. The satellites are tracked as standalone Global Positioning System (GPS) satellite and as GPS and Global Navgation Satellite System (GLONASS) combined. A ground surveying method using total station is also employed to run traverse and leveling on the same points for the purpose of comparison of the results. The GNSS observations were accomplished using Hi target V30 while traversing and leveling were carried out using a South NTS 352 total station instrument. The observations were done on the same points with the two instruments which give three sets of data comprising of planimetric and vertical coordinates. Discrepancies among the data set were obtained and subjected to statistical test. The result shows some discrepancies among the data sets, the statistical test indicated a significant difference among the methods and data of the three methods on the planimetric coordinates. However in the vertical coordinates, the methods show no significant difference but the vertical coordinate showed a significant difference among the three data sets.

Keywords: GNSS, Precise Point Positioning, Static Mode, GLONASS, GPS, ANOVA

INTRODUCTION

Methods of satellite geodesy are increasingly used in geodesy, engineering surveying, and related disciplines. In particular, the modern development of precise and operational satellite based positioning and navigation techniques have entered all fields of geosciences and engineering (Gunter Seember, 2003). Global Navigation Satellite Systems (GNSS) consist of satellites, ground stations and user equipment and are utilized worldwide across many areas of society. The earliest Global Navigation Satellite Systems operating in different constellations, are the United States, the system has been continuously operated as a navigation system since 1980. The GPS system consist of 24 satellite in six earth-centered orbital plane, each with four satellite orbiting at 20,000km above earth and 12 hours orbital period (Byung *et al*., 2013).

The second fully deployed GNSS is the Russian system—GLONASS (Hofmann-Wellenhof *et al*. 2008:ICD-GLONASS 2008; Jeffrey 2015). It has full orbital constellation consisting of 24 satellites into three orbit planes. The orbit altitude is 19,100 km above the Earth’s surface with 11 hours 15 minutes orbital period (Iurii Cherniak & Irina Zakharenkova, 2017). The light launch of GLONASS was in 2007, after 2012 it successfully achieved a full operation and resumed precise positioning service along with the GPS (Byung *et al* 2013). The international GLONASS service in their pilot project has demonstrated that the satellite have large potential for precision navigation and positioning (Zarraoa *et al*., 1998).

Other GNSS system in operation consists of Europe's European Satellite Navigation Systems (GALILEO), and China's Compass/BeiDou are also a part of the Global Positioning System. Meanwhile, India's GPS Aided Geo Augmented Navigation (GAGAN) and Japan's Quasi-Zenith Satellite System (QZSS) are part of the Regional Navigation Satellite Systems (RNSS) which provides signal coverage over a number of nations or region. GNSS system works with signal it receives from satellite, this signal is further translated into useful data for the purpose of positioning. The signals are based on direct-sequence spread-spectrum (DS-SS) modulations and are characterized by an extremely low level of signal power, when they arrive at the receiving antenna. One of the first operations performed by GNSS receivers consists in the correlation between the received signals and local replicas of the carrier and spreading code. The signal correlation allows the acquisition of the satellites in view and the tracking of the signals over time, continuously estimating Doppler shift and code delay that are used to compute the pseudo ranges.

There are three primary methods of GNSS observation, these includes static baseline, real Time kinematics (RTK) and the continuously operating reference system (CORS). The static baseline mode uses one stationary receiver and at least one moving receiver called a rover. All the receivers observe the same satellites simultaneously, and the reference receivers occupy the same control points throughout the survey. The rover antenna moves from point to point across the network. They stop momentarily at each new point for about 5 to 20 minutes and their data eventually provide vectors between themselves and reference receivers. Static baseline mode of observation is widely used to calculate high-precision coordinates of traverse stations in three dimensions. The system gives coordinates of points at a millimeter level both in the horizontal and vertical components (Nixon et al 2018). The main applications of static mode of GNSS observation is in setting control points for monitoring deformation of structures (Rizos et al., 2003), as well as constructing base traverses for linear objects such as roads, railways and flow media lines (Zhang et al., 2014). Real time kinematics observation (RTK) is also used in the determination of planimetric and vertical coordinates of points using two receivers. RTK operates by measuring distance between the base station and the second receiver; it uses multiple points in quick succession to determine position. The method of RTK is nearly as accurate as the static mode but is limited to a range of about 20 km. Continuously operating reference system (CORS), on the other hand operates using the same principles as the other techniques mentioned above. The difference is that the same station is installed in a permanent known location; this allows measurements to be taken at any point in the district using the permanent base station as a starting point. CORS are commonly used for major engineering projects that require continues surveying over a long period of time.

The three different GNSS observation system listed above works with the available satellites in different constellations. These satellites constellations are standing separately and can be used as standalone for point positioning, the combination of the two sets will normally improve the number of satellites tracked and will give a better geometry and as a result improve the accuracy of the result (Hofmann-Wellenhof, 2007: Takana et al 2017). In their research, Pandey et al

(2019) and Gabriel and Daniele (2019) shows that precise point positioning using the combination of GPS and GLONASS satellite shows an improvement in the result over the standalone GPS under different condition. Ali (2017), Solomon (2014) in their separate research concluded that the ground survey method using total station is of better accuracy compared to GPS system in position fixing. Although the satellites in their different constellation are readily and always available for tracking and use for GNSS coordinate determination, it is important to know the variation in coordinates obtained when tracking separate constellation or the combine constellation. This will be helpful in making decision of which satellite constellation is to be tracked during observation or situations of political disagreement that may prevent the availability of the two constellations at the same time.

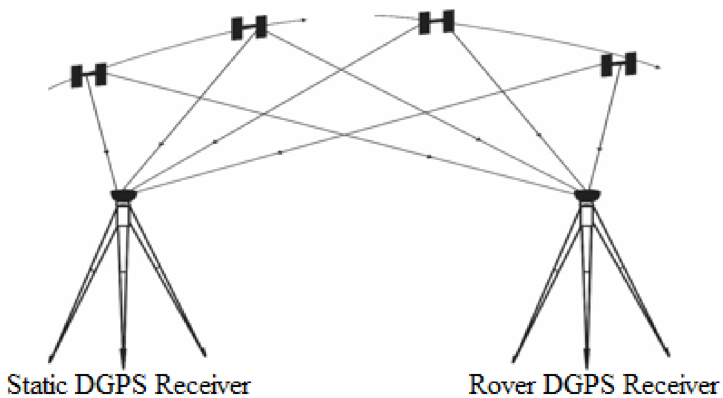

Figure 1: Arrangement of rapid static GNSS method of observations

In this research, the static GNSS mode of observation is used; the choice is simply for better accuracy and convenience of the researchers in achieving the goals of the research. The satellites are tracked as standalone GPS satellite and as a combination of GPS and GLONASS. In the same vein, in order to see the deviation of the GNSS system when tracking the two different constellations (GPS and GPS and GLONASS) from the ground surveying methods, a total station is also employed to run traverse and leveling on the same points for the purpose of comparison.

The study area

The study area was deliberately chosen in Modibbo Adama University of Technology (MAUTECH) Yola in Adamawa State, Nigeria to serve as demonstration site in explaining the behaviors of the three different observations. The area has an open space and another covered by trees; this is to also confirm the behavior of the GNSS observation under a covered sky. The place is located between Easting 223754.506m, Northing 1034651.108m and Easting 22538.957m, Northing 103393.516m based on the world geodetic system of 1984 (WGS 84).

METHODOLOGY

A dual frequency GNSS receiver (Hi-target V 30) and a total station (South NTS 352) were used to obtain data. The GNSS receiver was used for observation in rapid static mode the total station for traversing and leveling. The almanac of the GPS and GPS and GLONASS constellations was checked to get the best time for observations. Two control points were established within the study area (HCP_1, HCP_2,) in addition to an existing one (MCP 03) earlier established. For

Figure 2: Points of observation at the study area

the purpose of this research nine points (P_1 to P_9) were chosen for observation to allow for easy and simple demonstration and assessment of the three methods of point positioning under consideration. A dual frequency GNSS receiver was set on the rapid static mode of observations with the base set on HCP_1 whereas the rover moves successively on points P_1 to P_9. At each point, GPS and GPS and GLONASS signals were tracked at a spot and the coordinates were recorded at intervals of 2 seconds for a period of 5 minutes. Consequently traversing and leveling were also carried out on the same nine points with a total station using the reference (MCP 03 and HCP_1).

The observed data were grouped into three ranging from A to C. Data A is the X, Y, Z coordinates of points observed on rapid static mode when tracking only GPS signals, data B is the data when tracking GPS and GLONASS signal, and data C is the one obtained with total station from leveling and traversing operation.

Data processing

Hi-target geomatics solutions (HGS) was used to process data when selecting only GPS constellation so as to get the adjusted GPS coordinates (data A), the same was used in the adjustment when selecting GPS and GLONASS constellation to get the adjusted coordinates (data B). The ellipsoidal heights obtained during GNSS observation were consequently converted to orthometric height during processing with HGS. In addition, Microsoft Excel 2016 was used for editing the data that was utilized in Auto-CAD 2014 and surfer 10 for assessment and plotting. In order to evaluate the performance of all the methods used and the result they produced in this research, Analysis of variance (ANOVA) was utilized; this was achieved by finding the discrepancies between the data sets obtained by the three methods followed by other analysis as seen below:

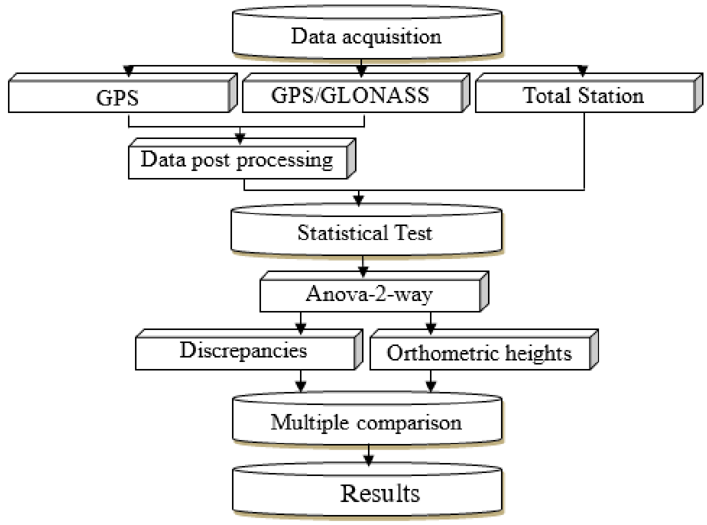

Figure 3: Methodology chat of the research

Discrepancies between data A and data B

$$\Delta x = \begin{bmatrix} x_{B1} - x_{A1} \\ x_{B2} - x_{A2} \\ \vdots \quad \vdots \\ x_{B9} - x_{A9} \end{bmatrix} = \begin{bmatrix} \Delta_{x1} \\ \Delta_{x2} \\ \vdots \\ \Delta_{x9} \end{bmatrix} \quad \Delta y = \begin{bmatrix} y_{B1} - y_{A1} \\ y_{B2} - y_{A2} \\ \vdots \quad \vdots \\ y_{B9} - y_{A9} \end{bmatrix} = \begin{bmatrix} \Delta_{y1} \\ \Delta_{y2} \\ \vdots \\ \Delta_{y9} \end{bmatrix} \; \Delta = \begin{bmatrix} \left[(\Delta_{x1})^2 + (\Delta_{y1})^2\right]^{1/2} \\ \left[(\Delta_{x2})^2 + (\Delta_{y2})^2\right]^{1/2} \\ \vdots \quad \vdots \\ \left[(\Delta_{x9})^2 + (\Delta_{y9})^2\right]^{1/2} \end{bmatrix}$$

Where: Δx is the vector of the differences on x coordinates of point 1 to 9 obtained from method A and B, Δy is the vector of the differences on y coordinates of point 1 to 9 obtained from method A and B. Δ is the vector representing the discrepancies between the horizontal coordinates obtained from method A and B.

Discrepancies between Group A and Group C

$$\Delta x = \begin{bmatrix} x_{C1} - x_{A1} \\ x_{C2} - x_{A2} \\ \vdots \quad \vdots \\ x_{c9} - x_{A9} \end{bmatrix} = \begin{bmatrix} \Delta_{x1} \\ \Delta_{x2} \\ \vdots \\ \Delta_{x9} \end{bmatrix}, \Delta y = \begin{bmatrix} y_{C1} - y_{A1} \\ y_{C2} - y_{A2} \\ \vdots \quad \vdots \\ y_{C9} - y_{A9} \end{bmatrix} = \begin{bmatrix} \Delta_{y1} \\ \Delta_{y2} \\ \vdots \\ \Delta_{y9} \end{bmatrix}, \Delta' = \begin{bmatrix} \left[(\Delta_{x1})^2 + (\Delta_{y1})^2\right]^{1/2} \\ \left[(\Delta_{x2})^2 + (\Delta_{y2})^2\right]^{1/2} \\ \vdots \quad \vdots \\ \left[(\Delta_{x9})^2 + (\Delta_{y9})^2\right]^{1/2} \end{bmatrix}$$

Where: Δx is the vector representing the differences on x coordinates of point 1 to 9 obtained from method A and C. Δy is the vector representing the differences on y coordinates of point 1 to 9 obtained from method A and C. Δ' is the vector representing the discrepancies between the horizontal coordinates obtained from method A and C

Discrepancies between Group B and Group C

$$\Delta x = \begin{bmatrix} x_{C1} & - & x_{B1} \\ x_{C2} & - & x_{B2} \\ \vdots & & \vdots \\ x_{c10} & - & x_{B9} \end{bmatrix} = \begin{bmatrix} \Delta_{x1} \\ \Delta_{x2} \\ \vdots \\ \Delta_{x9} \end{bmatrix} \Delta y = \begin{bmatrix} y_{C1} & - & y_{B1} \\ y_{C2} & - & y_{B2} \\ \vdots & & \vdots \\ y_{C9} & - & y_{B9} \end{bmatrix} = \begin{bmatrix} \Delta_{y1} \\ \Delta_{y2} \\ \vdots \\ \Delta_{y9} \end{bmatrix} \Delta'' = \begin{bmatrix} \left[(\Delta_{x1})^2 + (\Delta_{y1})^2\right]^{1/2} \\ \left[(\Delta_{x2})^2 + (\Delta_{y2})^2\right]^{1/2} \\ \vdots \quad\quad \vdots \\ \left[(\Delta_{x9})^2 + (\Delta_{y9})^2\right]^{1/2} \end{bmatrix}$$

Where: Δx is the vector representing the differences on x coordinates of point 1 to 9 obtained from method B and C. Δy is the vector representing the differences on y coordinates of point 1 to 9 obtained from method B and C. Δ'' is the vector representing the discrepancies between the horizontal coordinates obtained from method B and C.

The ANOVA two-way test was conducted on the discrepancies along the horizontal coordinate and on the discrepancies on the heights obtained from the methods.

Statement of hypothesis tested on the discrepancy

The objectives of the ANOVA tests were to check whether there was no significant difference between the means of the discrepancies obtained from the three methods. That is:

H_o: $\mu_1 = \mu_2 = \mu_3$

H_1: $\mu_1 \neq \mu_2 \neq \mu_3$

At 0.05 level of significance

Also to check whether there was no significant difference between the means of the discrepancies at each point. That is:

H_o: $\beta_1 = \beta_2 = \beta_3 \ldots\ldots = \beta_9$

H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \ldots\ldots \neq \beta_9$

At 0.05 level of significance

Statement of the hypothesis tested on the heights

Statement of the hypothesis tested on the ellipsoidal heights. The objectives of the tests were:

a) To check whether there was no significant difference between the means of the ellipsoidal heights obtained from the two methods, that is:

   H_o: $\mu_1 = \mu_2 = \mu_3$

   H_1: $\mu_1 \neq \mu_2 \neq \mu_3$

   At 0.05 level of significance

b) To check whether there was no significant difference between the ellipsoid heights obtained at each point. That is:

H_o: $\beta_1 = \beta_2 = \beta_3$ ….. $= \beta_9$

H_1: $\beta_1 \neq \beta_2 \neq \beta_3$ ….. $\neq \beta_9$

At 0.05 level of significance

Multiple comparisons test

This test was carried out because the null hypothesis was rejected. This is to detect the readings which are causing much effect. This procedure uses the t statistic for testing $H_o : \mu_i = \mu_j$.

$$t_o = \frac{\bar{y}_{i.} - \bar{y}_{j.}}{\sqrt{MSE\left(\frac{1}{n_i} - \frac{1}{n_j}\right)}}$$

RESULTS AND DISCUSSION

Results show coordinates obtained when tracking only GPS signal (Table 1), and Coordinates obtained when tracking both GPS and GPS/GLONASS (Table 2). Coordinates obtained from traversing and levelling using total station are shown in Table 3. The average of 6 GPS satellite and 12 GPS and GLONASS satellite were tracked during the observation (table 4). This shows that there were more GPS and GLONASS satellite than the GPS satellites standalone during the observations. It is obvious because the combination of the two constellations in space will always yield more number of satellites at a time (Pandey et al 2016).

Table 1: Coordinates of points obtained when tracking only GPS signal

Points	X	Y	H
P1	6145090.1741	1361739.9070	224.0028
P2	6145052.0836	1361884.1142	226.1467
P3	6145037.2619	1361988.5194	228.2215
P4	6145026.1498	1362071.8439	229.5647
P5	6145027.0143	1362107.6764	227.2314
P6	6145056.3548	1362088.8182	233.8219
P7	6145070.6168	1362031.9374	231.9856
P8	6145099.1894	1361927.4087	236.9812
P9	6145112.0468	1361805.4677	230.7429

Table 2: Coordinates of points obtained when tracking both GPS and GPS/GLONASS signals

Points	X	Y	H
P1	6145096.3949	1361745.32	231.2179
P2	6145057.0172	1361889.242	232.2048
P3	6145041.5140	1361993.112	233.1963
P4	6145031.0779	1362076.491	234.4337
P5	6145030.4514	1362113.626	231.0418
P6	6145057.7280	1362091.236	235.5823
P7	6145076.2072	1362038.46	238.4211
P8	6145102.1052	1361933.819	241.6204
P9	6145116.0536	1361811.922	236.1789

In table 5, the maximum discrepancy between the horizontal coordinates of the same point is recorded at P7 as 8.591m between GPS and GPS and GLONASS methods, while the minimum discrepancy value is recorded at P9 as 0.479m between GPS and GLONASS combine and traversing and leveling methods (table 5). The maximum discrepancy at P7 may be due to the fact that the combination of GPS and GLONASS satellite constellation gives a better PDOP and geometry of the satellite than GPS standalone (Pandey et al 2016 and Gioia, 2013) and therefore the two results will not be in agreement. The minimum discrepancy recorded at P9 shows that the two methods of positioning seem to closely agree. Since traversing with total station instrument which is a ground survey method is seen by Ali (2017) and Solomon (2014) to be of good accuracy while the combination of GPS and GLONASS observation give an improved satellite geometry and PDOP and consequently gives a better result (Pandey et al 2016). The result obtained by total station and GPS and GLONASS observation will certainly look similar.

Table 3: Coordinates of points obtained from traversing and leveling

Points	X	Y	H
P1	6145096.5594	1361743.9010	232.6616
P2	6145054.6284	1361889.1730	234.2260
P3	6145040.0199	1361992.8878	233.3502
P4	6145031.6495	1362076.0228	235.9207
P5	6145030.8117	1362111.6495	230.7277
P6	6145058.6638	1362090.4675	237.4984
P7	6145073.2959	1362038.9348	239.9746
P8	6145103.0183	1361932.6272	243.2100
P9	6145116.4404	1361811.6387	237.3614

Table 4: Number of satellites tracked and PDOP obtained at each point by each method.

	GPS method		GPS/GLO method	
Points	Numb of sat	PDOP	Num of sat	PDOP
P1	7	1.6	14	1.3
P2	7	1.6	14	1.3
P3	7	1.6	13	1.2
P4	6	1.7	10	1.4
P5	5	1.6	10	1.2
P6	6	1.7	10	1.4
P7	6	2	10	1.3
P8	6	3	12	1.5
P9	7	1.9	13	1.4
Average	6	1.9	12	1.3

The average discrepancy between GPS and GPS and GLONASS combine, GPS and traversing and leveling and GPS and GLONASS and traversing and leveling in planimetric coordinates of the same point are 6.808m, 6.127m and 1.580m respectively. This may be so because of the fact explained above and can also be summarized that the combination of GPS and GLONASS observation gives better result as the ground survey method of traversing and leveling with total station than the GPS standalone. This may be why the average discrepancy between GPS standalone and GPS and GLONASS (6.808), GPS standalone and traversing and leveling (6.127) is seen to be higher than the average discrepancy between the other two better methods (GPS and GLONASS and traversing and leveling) which is 1.580. The discrepancies are also represents on bar chart in Figure 4. The blue color represents the discrepancy between GPS and GPS and GLONASS, the red color represents the discrepancy between GPS and traversing and leveling while the yellow color represents the discrepancy between GPS and GLONASS and traversing and leveling.

Table 5: Discrepancies in horizontal coordinates of points obtained at each method.

Points	Δ	Δ′	Δ″
P1	8.246342797	7.531539821	1.42880115
P2	7.11609754	5.662814184	2.3898079
P3	6.259073686	5.166186462	1.51088715
P4	6.773466559	6.907235721	0.73874932
P5	6.870968393	5.495977654	2.00897313
P6	2.780632779	2.837546738	1.21097795
P7	8.590663071	7.49274206	2.94973098
P8	7.042289097	6.472497003	1.50137898
P9	7.596445266	7.575286263	0.47915559

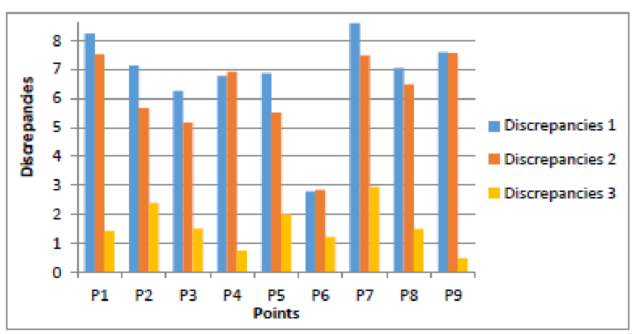

Figure 4: Discrepancies of the horizontal coordinates

Table 6 is the result of the ANOVA two-way test; it shows that there is a significant difference among the discrepancies between the methods used. This may be because of the earlier reasons stated above. The result of the multiple comparison tests at 0.05 level of significance however shows all the mean discrepancies at each point are equal except means at P7 and P8. Points P7 and P8 are situated under trees, the obstructed sky during the GNSS observation could be reason for the variation in mean discrepancies on the two points.

Table 6: Results of the ANOVA test on discrepancies

Source	Sum of Square	Df	Mean Square	F	P-value
Raw	145.436	2	72.718	72.882	.000
Column	30.407	8	3.801	3.809	.011
Error	15.964	16	.998		
Total	823.874	26			

The heights obtained from leveling with total station are closer to that obtained by GPS and GLONASS combine observation (figure 5). This will also be attributed to the fact that the two methods are seem to be better than the GPS standalone in terms of positioning as earlier mentioned above.

Table 7 shows the result of the ANOVA test, it shows no significant difference among the methods used and a significant difference among the heights obtained from the three methods. The no significant difference in the three methods used may suggest that, although the three methods yield different heights at each point, but the result follow the same pattern as can be seen in figure 5 above. However, the significant difference noticed among the heights of the same point from the three methods may likely be due to the fact that tracking GPS with fewer satellite constellation will not give good result in height as tracking GPS and GLONASS combined because of the obvious reasons as supported by Pandey et al (2016) and Gioia, (2013). Although GPS and GLONASS combine with leveling by total station seem to agree as indicated on the chart in figure 5, combining the three heights will certainly shows a significant difference in the heights obtained.

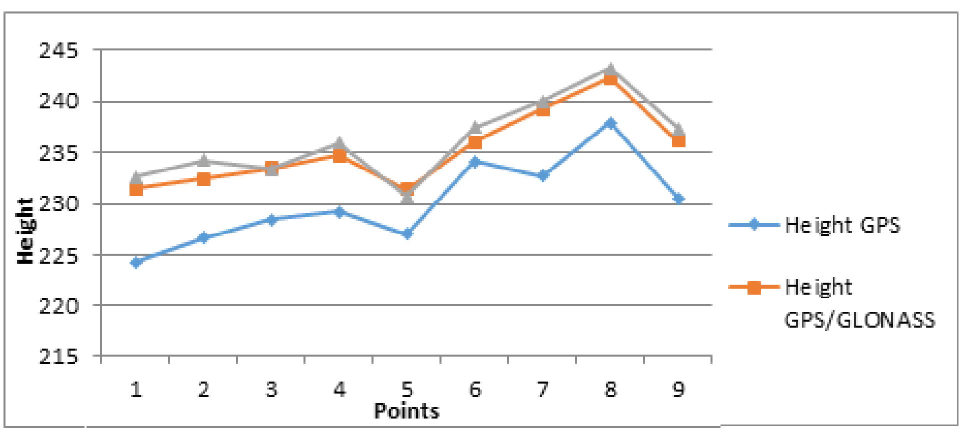

Figure 5: Heights by each method

Table 7: Result of the ANOVA test on heights.

Source	Sum of Square	Df	Mean Square	F	P-value
Raw	0.001	1	.001	0.001	.976
Column	185481.116	8	23185.139	35957.965	.000
Error	5.158	8	.645		
Total	185486.275	17			

CONCLUSION

Point positioning while tracking GPS and GPS/GLONASS satellite has shown a wide difference in the resultant coordinates. Tracking of satellite under the same condition and time proves to show variation in the number of satellite tracked at the same time for the two methods. The number of satellites tracked does not necessarily guarantee a good PDOP for both campaign and that GPS/GLONASS constellation seems to have a better PDOP than GPS constellation during the observation period. Result obtained by traversing/leveling using total station seems to be closer to the one obtain while tracking GPS/GLONASS satellite constellation. This has further demonstrated clearly that point positioning while tracking GPS/GLONASS satellite constellation yield a better result than when tracking GPS satellite constellation alone. It is therefore always advisable to resort to point positioning while tracking GPS/GLONASS for an improved result.

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