The Impact of an Integrated GPS and GLONASS Satellite Geometry in the Precision of Positioning

Oluropo OLAJUGBA and Chika OKOROCHA, Nigeria

Keywords: Integrated, GPS, GLONASS, Geometry, Positioning

SUMMARY

The satellite geometry constitutes a major factor in determining the precision of satellite based positioning system. In precise point positioning as well as differential positioning, the number of visible satellites affect the satellite geometry which in turn affects Position Dilution of Precision (PDOP) and subsequently precision in positioning. In the use of GPS only observations in areas such as urban canyons, mountains and open-pit mines, satellite visibility by the GPS receiver is greatly reduced as multipath effect is very high. This underscores the need to integrate GPS and GLONASS observations to improve the satellite visibility and Geometry. The research focuses on differential observations carried out on 23 secondary control points within University of Lagos, Nigeria, using a GNSS receiver in static mode with a Primary control XST347 as base reference. The results were post processed using only the GPS observations and then integrated with the GLONASS observations. Although, Differential observation increases accuracy in satellite positioning, but the integrated observation was found to have higher number of visible satellite, better geometry and PDOP, lower standard error in range measurement and positioning. The following average percentage improvement were achieved across the observed stations with an integrated GPS and GLONASS geometry; 35.90% increase in satellite visibility, 30.06% decrease in PDOP and 36.19% decrease in standard error in relative positioning. A One Way ANOVA statistical test was further conducted to justify the improvement precision of the integrated system at 0.05 significant level (95% confidence interval). This shows a significant difference between the standard error in relative positioning for the GPS only observation as against the integrated system which is apparent in the percentage precision improvement. The research has justify the need for continuously growth in the GNSS technology with other satellite constellation like the Galileo and Compass becoming fully operational and available to the general public the level of attainable positioning accuracy and precision would be really interesting even in real time positioning.

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1. INTRODUCTION

The fundamental technique of GPS is to measure the ranges between the receiver and a few simultaneously observed satellites to unknown positions on land and sea, as well as in air and space. The positions of the satellites are forecasted and broadcasted along with the GPS signal to the user. Through several known positions (of the satellites) and the measured distances between the receiver and the satellites, the position of the receiver can be determined (Xu, 2007).

The Differential Global Positioning System (DGPS) involves position determination of a rover station with reference to a base station. Both the rover and base stations simultaneously observe the same positional satellites in space and necessary pseudo-range correction is effected on the position of the rover station with respect to the base station which could be post processed or real time by radio transmission. DGPS positioning could either be in static mode or in Kinematic mode. The purpose of Differential correction in DGPS positioning is to provide a higher accuracy in GPS position determination which is not achievable in Precise Point Positioning (PPP). DGPS positioning has applications in various field such as in dynamic positioning offshore for oil exploration, where it is serves as the positioning reference system, in construction industry, all forms of mapping activities, deformation monitoring, etc.

Furthermore, other satellite constellations beside the GPS have been developed and still in development; the Russian GLONASS, the European Galileo, the Chinese BeiDuo/COMPASS and the Japanese QZSS. Currently, there are three GNSS constellations that are fully operational (GPS, GLONASS, and QZSS) and two that are being actively deployed (COMPASS and Galileo). These have increased the number of available satellites and it is still increasing with the introduction of new and modernized satellite constellations. (Trimble, 2012)

The combination of these system in satellite based positioning have given rise to GNSS and now areas that were previously too obscured could be reached with modern GNSS rover. These multiple navigation systems operating independently help increase the awareness and accuracy of the real time positioning and navigation. A combined GNSS system which uses the GPS, GLONASS and Galileo systems together has a constellation of about 75 satellites. A constellation of 75 satellites increases satellite visibility of GNSS receivers especially in urban canyons (Xu, 2007).

GNSS technology has further more research in satellite based positioning system. The principle of operation of GPS in position determination has not changed in GNSS but an expectation of achieving greater accuracy and precision with GNSS is envisage. Baseline

processing, the fundamental principle of satellite based positioning is still applicable with the GNSS system in both static post processing operations and real time operations.
The Global Navigation Satellite System has dramatically changed the way that surveyors and other professional engineers measure positional coordinates. These experts can now measure spatial distances – baselines and estimate 3D coordinates of a new point (rover) relative to a reference located from a few to many tens of kilometers away (Fotiou, et al 2006).

This range/baseline defined by the distance between the rover and the base station is a position vector whose origin is at the base station. Thus, the position vector of the rover station defines the DGNSS baseline (range vector). In DGNSS positioning, the increase in the baseline affects the accuracy of the determined position and this accuracy is also a function of the satellite geometry. It is also worthwhile to note that satellite geometry has an amplifying effect on other GNSS sources of error (Lonchay, 2009).

The amplifying effect of the satellite geometry on other sources of error led to this research to determine the level of impact an integrated GPS and GLONASS satellite geometry has over a GPS only Satellite geometry in positioning. The research was carried out on 23 secondary control points within University of Lagos, Lagos State, Nigeria. The research scope covers static observation and differential post processing correction utilizing only GPS satellite Geometry and subsequeutly integrating the GLONASS satellite geometry with the GPS to determine the impact level in positioning.

2.0 THE SATELLITE GEOMETRY

The nature of the GPS satellite constellation is of particular interest when considering the use of the system to determine height. The constellation consists of at least 24 operational satellites, which are divided into 6 orbital planes evenly spaced about the equatorial plane (Hamish, 2004).
The orbital planes contain 4 satellites that are inclined at 55° with respect to the equatorial plane. As a result, the satellites that are visible to the observer are a function of both the 55° inclination of the satellite orbital planes and the observer's latitude (Hamish, 2004).
For instance, an observer at latitude 90° south cannot view any satellites above a 45° elevation mask due to the 55° orbital inclination (see Figure 1a). Conversely, an observer at latitude 45° south cannot satellites in a southern direction except at elevations very close to the zenith (see figure 1b) (Hamish, 2004)

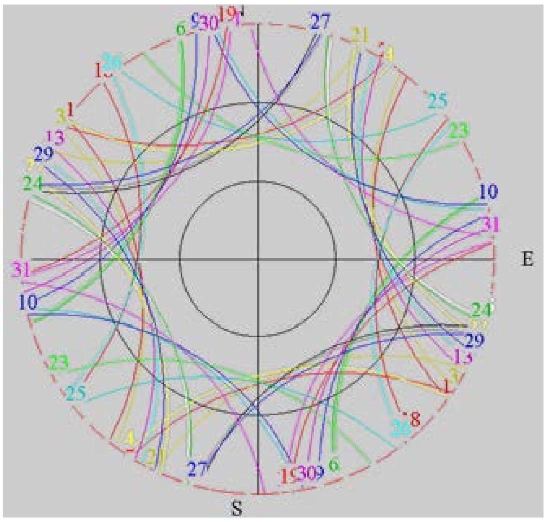

Figure 1a: Sky plot of visible satellites at 90°south

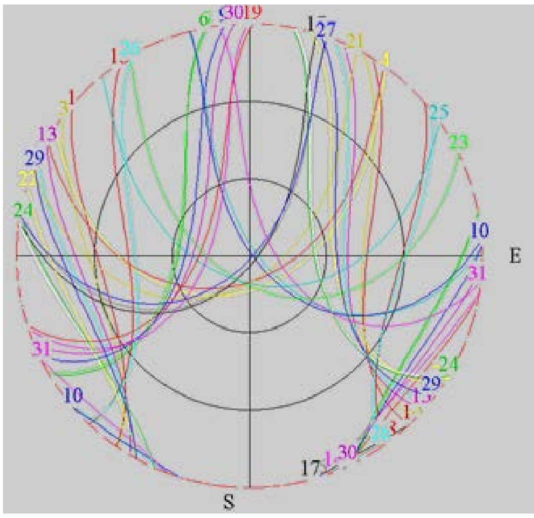

Figure 1b: Sky plot of visible satellites at 45°south (Source: Hamish, 2004).

The geometry of satellites, or lack of it, has obvious implications with regard to positioning. If one wishes to attain a reliable vertical solution, the geometry of the satellites being observed is critical. As with terrestrial resections, a well-defined solution requires a good geometrical spread of control stations about the unknown point. In the case of a GPS derived position there are no satellites available below the horizon. This induces a bias into the vertical component making height determination less precise than horizontal (Hamish, 2004).
Figures 1a and 1b highlight the problems faced by those wishing to make GPS observations to determine precise height. When making observations at 90° south the solution is weakened by the lack of satellites towards the zenith while at 45° south the solution is weakened by the lack of satellites in the southern direction. When making observations over a prolonged period, such as 24 hours, many satellites rise and set. Accordingly, geometry does not play the same role as it may if one were undertaking observations over a shorter duration (Hamish, 2004).

3.0 DILUTION OF PRECISION (DOP)

If one considers that the design matrix needed to construct the normal equations for a least squares solution, in addition to the systematic errors of the observations, is a function of the satellite observation direction then it is clear that satellite sky distribution plays an important part in the propagation of errors with respect to unknown parameters (Santerre, 1991)
The DOP factors are derived from the inverse of the unweighted normal equation matrix used to determine position and as such are strictly geometrical indicators of satellite suitability for positioning. The GDOP, PDOP and TDOP are determined from the cartesian coordinates in the World Geodetic Reference System 1984 (WGS84) while the HDOP and VDOP factors are derived from the transformed horizontal and vertical components in terms of the local system being used (Hofmann-Wellenhof et al 2001).

DOP is an indicator of the quality of the geometry of the satellite constellation. The computed position can vary depending on which satellites you use for the measurement. Different satellite geometries can magnify or lessen the errors in the error budget described above. A greater angle between the satellites lowers the DOP, and provides a better measurement. A higher DOP indicates poor satellite geometry, and an inferior measurement configuration (Corvallis, 2000)

Some GPS receivers can analyse the positions of the satellites available, based upon the almanac, and choose those satellites with the best geometry in order to make the DOP as low as possible. Another important GPS receiver feature is to be able to ignore or eliminate GPS readings with DOP values that exceed user-defined limits. Other GPS receivers may have the ability to use all of the satellites in view, thus minimizing the DOP as much as possible. DOP could be in form of PDOP, TDOP, or GDOP (Corvallis, 2000).

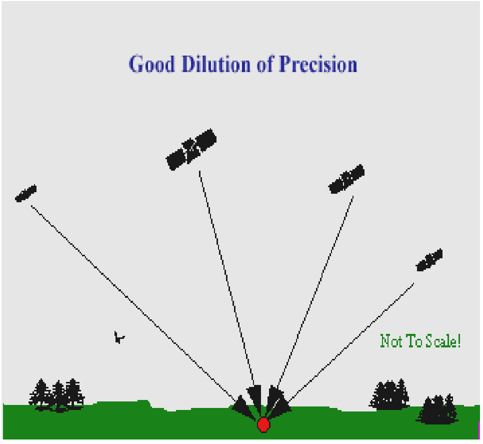

Figure 2a: Satellite Arrangement for Good DOP

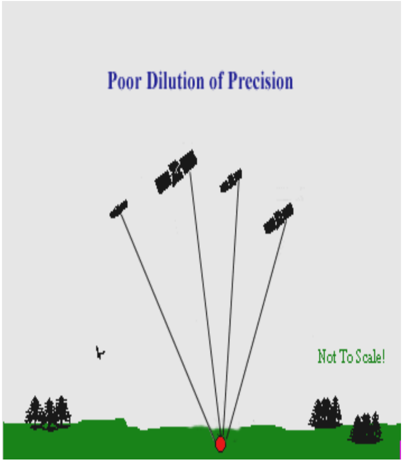

Figure 2b: Satellite Arrangement for Good DOP

(Source: Corvallis, 2000)

4.0 COMPUTATION OF STANDARD ERROR IN RELATIVE GNSS POSITIONING

The general principle of relative positioning also presented by Lonchay, (2009) is thus:

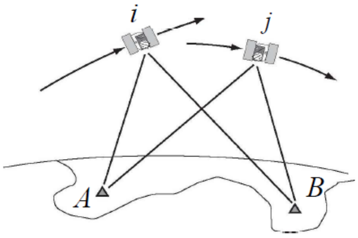

Figure 4: Relative GNSS Positioning (Source: Lonchay, 2009)

$$P^{ij}_{AB}(t) = P^{i}_{AB} - P^{j}_{AB} = D^{ij}_{AB} + T^{ij}_{AB} + I^{ij}_{AB} + M^{ij}_{AB,m} + \varepsilon^{i}_{AB,m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

T^{i}_{AB} = Tropospheric Delay

I^{i}_{AB} = Ionospheric Delay

$M^{i}_{AB,m}$ = Multipath Delay

$\varepsilon^{i}_{AB,m}$ = Noise

$$D^{ij}_{AB} = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2 + \left(Z_A - Z_B\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

There is no effect of satellite and receiver clock errors because relative GNSS positioning provides correction for these errors.

The standard error in relative positioning δ_{RPOS} is a function of both the relative dilution of precision (represented as maximum PDOP from research) and the standard error in range measurements (baseline length) between the base and the rover stations simultaneously acquiring GNSS satellite ephemeris.

Thus: $$\delta_{RPOS} = RDOP\delta_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where: δ_{RPOS} = Standard error in relative positioning
RDOP = Relative Dilution of Precision
δ_r = Standard error in range or baseline measurements

5.0. DATA COLLECTION AND PROCESSING

The process of Fast Static survey was done uninterruptedly for a minimum period of 30 minutes for each session using a Trimble R5 GNSS receiver. The base on station XST 347 was left static throughout the whole period of data collection while the rover stations were changed after each rover station occupation session.

GNSS survey involving differential correction requires a simultaneous observation of the same satellites by both the rover and base stations for successful baseline processing. This necessitated the continuous operation of the base station throughout the survey.

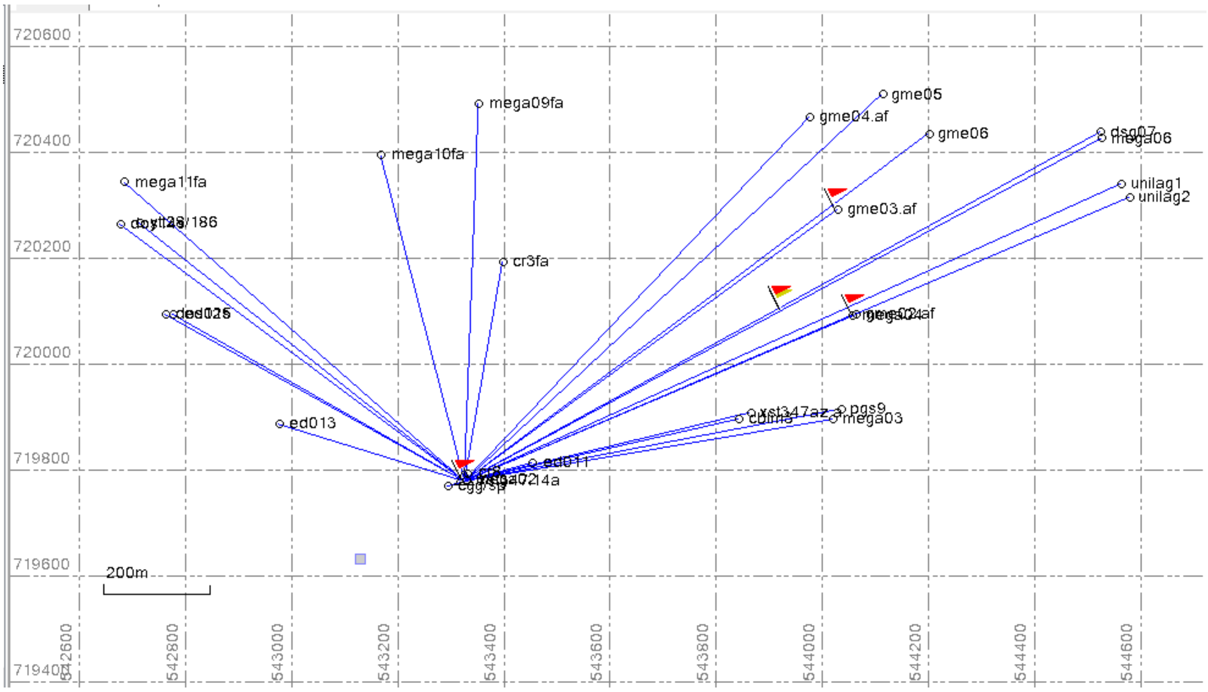

Figure 5: Showing GNSS Processed baselines (Source: Authors' Research)

6.0 RESULTS AND ANALYSIS

6.1. Results

Table 1: Baselines Processing Results of Selected Stations for GPS only Observation Satellite Geometry

Station From	***Station To***	***Easting(m)***	***Northing(m)***	***Elevation (m)***	***Horizontal Precision (m)***	***Vertical Precision (m)***
xst347	unilag1	544562.149	720340.233	9.099	0.011	0.018
xst347	mega11	542682.083	720343.786	13.138	0.027	0.035
xst347	mega10	543166.382	720394.636	14.29	0.009	0.013
xst347	mega09	543350.821	720492.220	13.95	0.005	0.009
xst347	cr3	543396.378	720193.587	6.405	0.009	0.013
xst347	gme04	543974.478	720466.068	14.451	0.01	0.017
xst347	gme03	544027.960	720292.095	13.733	0.005	0.01
xst347	gme02	544061.075	720092.373	13.519	0.008	0.013
xst347	ytt28/186	542710.626	720266.009	14.276	0.01	0.017
xst347	dos14s	542673.858	720264.736	14.017	0.004	0.007
xst347	dos12s	542760.028	720093.306	13.902	0.009	0.015
xst347	ed015	542774.067	720093.670	13.859	0.005	0.008
xst347	ed013	542973.939	719885.633	13.073	0.002	0.003
xst347	mega04	544055.292	720091.851	15.329	0.006	0.009

xst347	pg09	544033.217	719914.199	15.098	0.005	0.008
xst347	mega03	544018.137	719894.974	15.157	0.008	0.015
xst347	xst347az	543862.592	719907.627	11.599	0.002	0.004
xst347	cblm3	543840.047	719895.223	12.689	0.002	0.003
xst347	cr8	543329.834	719792.580	12.221	0.003	0.005
xst347	gme06	544199.282	720435.292	14.738	0.016	0.026
xst347	gme05	544111.792	720509.797	15.819	0.019	0.018
xst347	unilag2	544577.367	720314.280	8.958	0.007	0.011
xst347	cgg/sp	543292.257	719768.256	12.38	0.009	0.015

Table 2: Baselines Processing Results of Selected Stations for Integrated GPS + GLONASS Satellite Geometry

Station From	***Station To***	***Easting(m)***	***Northing(m)***	***Elevation (m)***	***Horizontal Precision (m)***	***Vertical Precision (m)***
xst347	unilag1	544562.147	720340.232	9.097	0.006	0.014
xst347	mega11	542682.084	720343.803	13.144	0.016	0.019
xst347	mega10	543166.382	720394.636	14.292	0.007	0.007
xst347	mega09	543350.824	720492.223	13.947	0.005	0.009
xst347	cr3	543396.378	720193.587	6.405	0.013	0.022
xst347	gme04	543974.477	720466.069	14.448	0.008	0.011
xst347	gme03	544027.960	720292.096	13.73	0.006	0.012
xst347	gme02	544061.078	720092.380	13.518	0.005	0.009
xst347	ytt28/186	542710.626	720266.009	14.278	0.009	0.008
xst347	dos14s	542673.858	720264.736	14.016	0.003	0.005
xst347	dos12s	542760.029	720093.302	13.883	0.011	0.018
xst347	ed015	542774.079	720093.673	13.875	0.005	0.008
xst347	ed013	542973.939	719885.633	13.073	0.002	0.002
xst347	mega04	544055.295	720091.851	15.328	0.008	0.009
xst347	pg09	544033.217	719914.200	15.099	0.004	0.007
xst347	mega03	544018.135	719894.976	15.161	0.008	0.014
xst347	xst347az	543862.593	719907.627	11.599	0.003	0.005
xst347	cblm3	543840.048	719895.225	12.689	0.002	0.003
xst347	cr8	543329.833	719792.580	12.222	0.003	0.005
xst347	gme06	544199.280	720435.292	14.741	0.012	0.019
xst347	gme05	544111.788	720509.792	15.82	0.017	0.016
xst347	unilag2	544577.367	720314.279	8.953	0.006	0.01
xst347	cgg/sp	543292.258	719768.257	12.38	0.006	0.008

Table 3: Showing GPS only Satellite Geometry Analysis and Standard Error in Relative Positioning

Station From	***Station To***	***Baseline Length (m)***	***Standard Error in Range (m)***	***Maximum PDOP***	***Number of GPS Satellite***	***Standard Error in Relative Positioning (m)***
xst347	unilag1	1359.815	0.003	3.005	7	0.009015
xst347	mega11	856.485	0.006	4.927	6	0.029562
xst347	mega10	636.87	0.002	2.093	8	0.004186
xst347	mega09	715.006	0.001	2.262	9	0.002262
xst347	cr3	424.517	0.002	2.474	8	0.004948
xst347	gme04	946.821	0.004	2.427	8	0.009708
xst347	gme03	871.543	0.002	2.256	9	0.004512
xst347	gme02	801.069	0.002	2.491	9	0.004982
xst347	ytt28/186	784.61	0.002	1.979	8	0.003958
xst347	dos14s	812.967	0.002	1.9	8	0.0038
xst347	dos12s	646.892	0.003	2.686	7	0.008058
xst347	ed015	634.875	0.002	5.629	10	0.011258
xst347	ed013	366.956	0.001	1.619	11	0.001619
xst347	mega04	795.549	0.003	2.596	7	0.007788
xst347	pg09	721.848	0.002	3.411	7	0.006822
xst347	mega03	703.592	0.003	2.337	7	0.007011
xst347	xst347az	553.597	0.001	2.398	9	0.002398
xst347	cblm3	528.813	0.001	1.71	11	0.00171
xst347	cr8	15.519	0.001	2.567	10	0.002567
xst347	gme06	1094.555	0.004	2.848	6	0.011392
xst347	gme05	1075.202	0.006	2.027	6	0.012162
xst347	unilag2	33.782	0.002	1.922	8	0.003844
xst347	cgg/sp	1363.241	0.003	1.685	8	0.005055

Table 4: Showing GPS + GLONASS Integration Satellite Geometry Analysis and Standard Error in Relative Positioning

Station From	***Station To***	***Baseline Length (m)***	***Standard Error in Range (m)***	***Max PDOP***	***No. of GPS Satellite***	***No. of GLONASS Satellite***	***Total Satellite Visibility***	***Standard Error in Relative Positioning (m)***
xst347	unilag1	1359.815	0.002	2.687	7	4	11	0.005374
xst347	mega11	856.485	0.004	2.379	6	4	10	0.009516
xst347	mega10	636.87	0.001	1.692	8	4	12	0.001692
xst347	mega09	715.006	0.001	1.788	9	5	14	0.001788
xst347	cr3	424.517	0.003	1.638	8	2	10	0.004914
xst347	gme04	946.821	0.003	1.624	8	4	12	0.004872
xst347	gme03	871.543	0.002	1.799	9	2	11	0.003598
xst347	gme02	801.069	0.001	1.647	9	2	11	0.001647
xst347	ytt28/186	784.61	0.003	1.636	8	4	12	0.004908
xst347	dos14s	812.967	0.001	1.56	8	5	13	0.00156
xst347	dos12s	646.892	0.004	1.671	7	6	13	0.006684
xst347	ed015	634.875	0.002	2.06	10	7	17	0.00412
xst347	ed013	366.956	0.001	1.248	11	8	19	0.001248
xst347	mega04	795.549	0.003	1.828	7	4	11	0.005484
xst347	pg09	721.848	0.002	1.805	7	4	11	0.00361
xst347	mega03	703.592	0.003	1.692	7	3	10	0.005076
xst347	xst347az	553.597	0.001	1.394	9	7	16	0.001394
xst347	cblm3	528.813	0.001	1.187	11	9	20	0.001187
xst347	cr8	15.519	0.001	1.335	10	7	17	0.001335
xst347	gme06	1094.555	0.003	1.986	6	4	10	0.005958
xst347	gme05	1075.202	0.005	1.601	6	6	12	0.008005
xst347	unilag2	1363.241	0.002	1.584	8	4	12	0.003168
xst347	cgg/sp	33.782	0.002	1.432	8	4	12	0.002864

Table 5: One Way ANOVA Results on the Standard Error in Relative Positioning (S.E.R.P) for the GPS System and the Integrated System

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000102348	1	0.000102	5.115813	0.028701	4.061706
Within Groups	0.000880275	44	2E-05			
Total	0.000982623	45				

6.2 Graphical Analysis

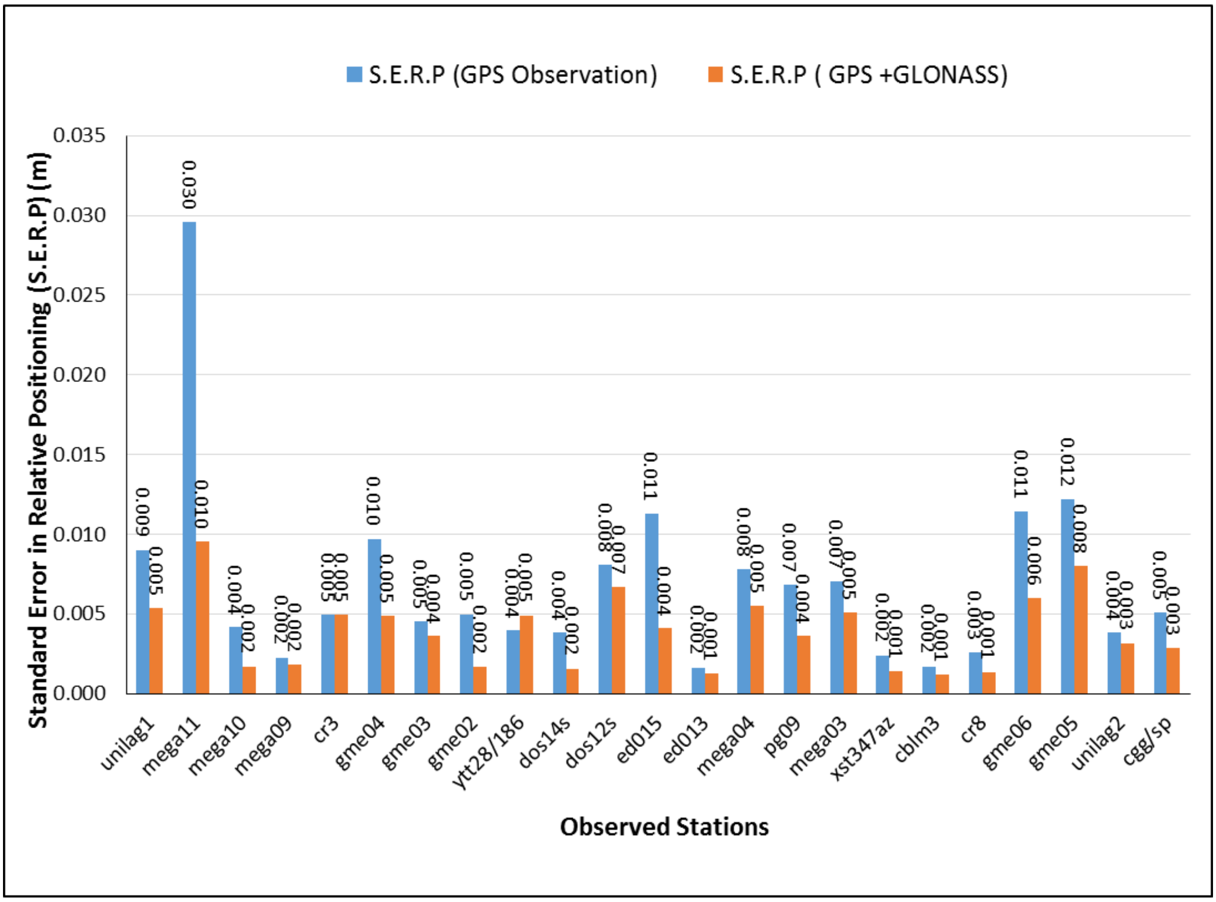

Figure 6: Showing Graphical comparison between S.E.R.P in the GPS System and GPS + GLONASS Integrated System.

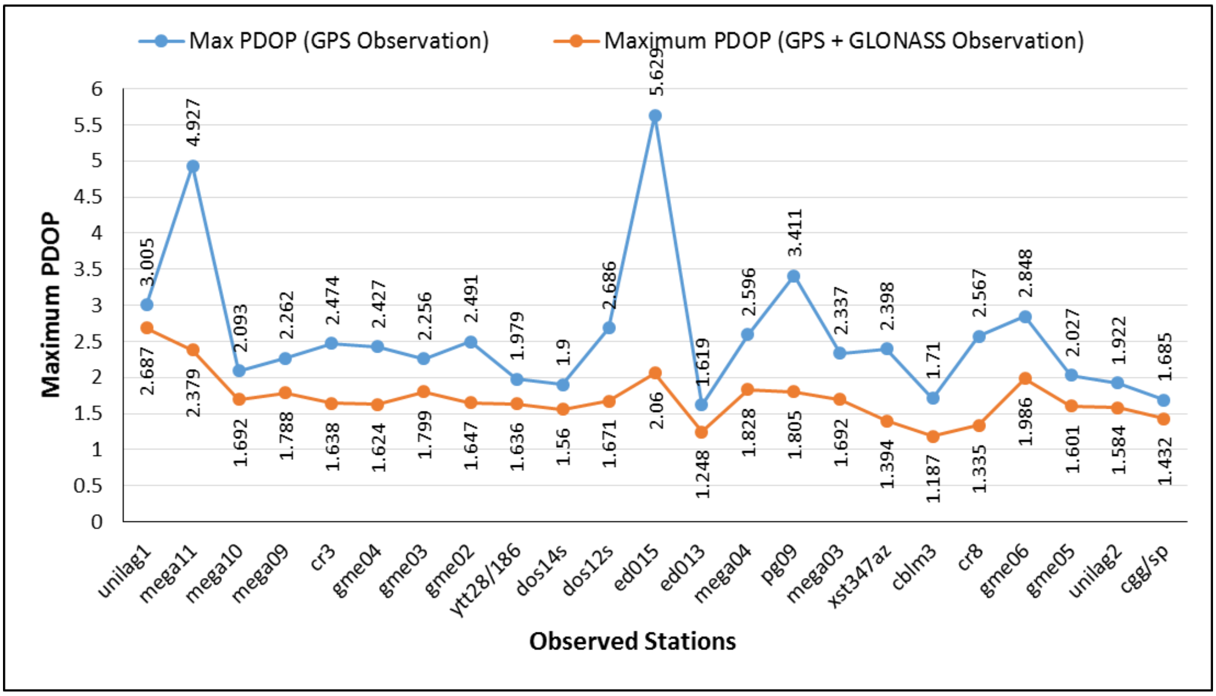

Figure 7: Showing Graphical comparison between PDOP in the GPS System and GPS + GLONASS Integrated System

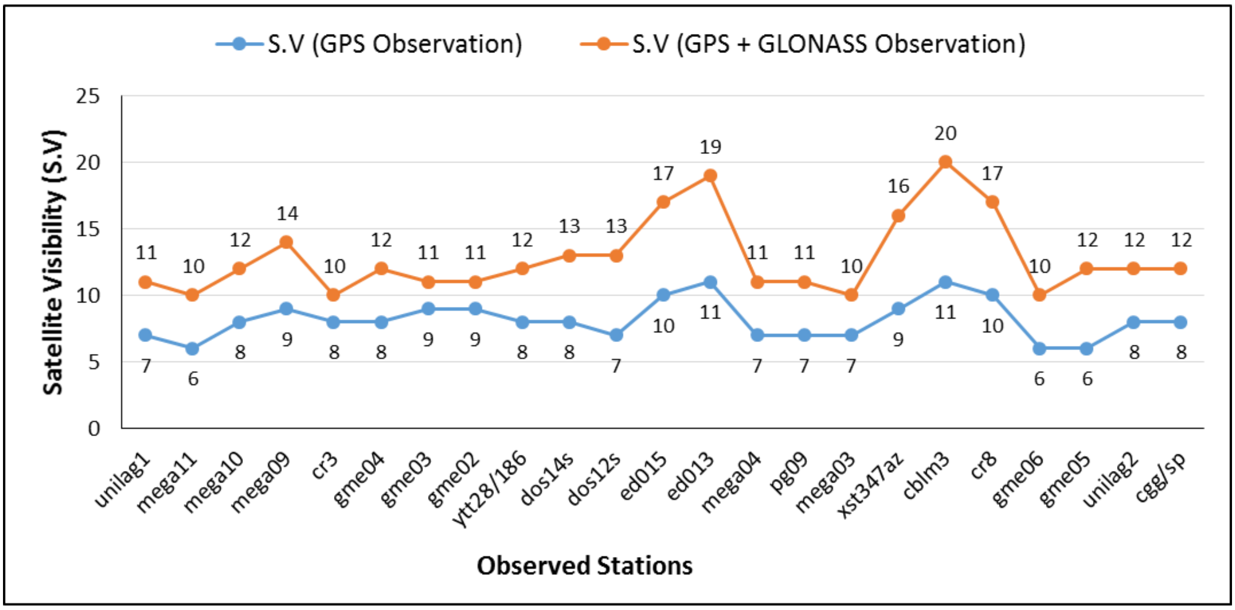

Figure 8: Showing Graphical comparison between Satellite Visibility in the GPS System and GPS + GLONASS Integrated System

6.3 Discussions

All results presentations were obtained from processed observations, analysis and computations. The tabular and graphical presentation of the results were necessary to ease interpretation

Tables 1 and 2 show the results of the spatial coordinates as well as resulting horizontal and vertical precision of GNSS processing of the observed stations applying only GPS satellite and integrating it with the GLONASS satellite geometry consecutively. The horizontal and vertical precision is a measure of accuracy in determining the X, Y, Z position of the observed stations. The closer the precision value to zero the higher the accuracy of the differential GNSS positioning.

Table 3 and 4 show a more detail analysis of the satellite geometry indicators; the PDOP, Number of Satellite Visibility and the standard error in range measurement. The PDOP and standard error in range measurement were used to compute the standard error in relative positioning as indicated in equation 2. Graphical illustrations in Figure 6, 7 and 8 further presents further comparism between the GPS only System and the GPS + GLONASS integrated system. All the graphical illustrations shows notable and obvious improvements in the integrated system. The following average percentage improvement were achieved across the observed stations with an integrated GPS and GLONASS geometry; 35.90% increase in satellite visibility, 30.06% decrease in PDOP and 36.19% decrease in standard error in relative positioning.

A One Way ANOVA statistical test was further conducted to justify the improvement precision of the integrated system at 0.05 significant level (95% confidence interval). The statistical test shows a significant difference between the standard error in relative positioning for the GPS only observation as against the integrated system which is apparent in the percentage precision improvement as well as graphical illustrations. The research has justify the need for continuously growth in the GNSS technology with other satellite constellation like the Galileo and Compass becoming fully operational and available to the general public the level of attainable positioning accuracy and precision would be really interesting even in real time positioning.

7.0 CONCLUSION

The research has justified the need for continuous development in GNSS. The growth and future of satellite positioning lies in a complete integration of all present and future satellite constellations. The integrated system shows an improvement in relative positioning accuracy by 36.19%. This improvement resulted from improvement in both the satellite visibility and the PDOP; with this improvement, positioning with high accuracy can be carried out in urban areas or areas where satellite visibility is obstructed. The integrated system of GPS and GLONASS satellite geometry has proven to be more superior to the GPS only geometry. This was also confirmed using the ANOVA one way statistical test.

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BIOGRAPHICAL NOTES

Chika. V. OKOROCHA is a Geospatial Manager in Lordsfield Limited. He holds a B.Tech and M.Sc. in Surveying and Geoinformatics and He is also a certified Project Manager. He specializes in the application of innovative geospatial solutions in handling all geospatial based projects in construction, oil and gas, surveying and mapping industries. He is a professional with a keen desire for excellence.

Oluropo OLAJUGBA is the Managing Director Lordsfield Limited. A company with various geospatial experts providing geospatial services to the construction, oil and gas, mapping, and surveying industries and has a wide range of clients from government agencies to multinational companies. He is a full member of the Nigerian Institution of Surveyors (NIS) and has held several positions in the regional and national level of the professional body. He holds the following qualifications: B.Sc. (Surveying and Geoinformatics), M.Sc. (Geographic Information System) and Masters in Business Administration (MBA).

CONTACTS

Chika. V. Okorocha (B.Tech, M.Sc)
Lordsfield Limited
4th Floor (Right Wing), Nigeria Institution of Surveyors House,
Opposite Elephant Cement House Assbifi Road,
CBD Alausa, Ikeja,
Lagos State.
Nigeria.
Tel: +2347030486687
Email: chikaokorocha@gmail.com

Surv. Oluropo Olajugba (B.Sc, M.Sc, MBA, Mnis)
Lordsfield Limited
4th Floor (Right Wing), Nigeria Institution of Surveyors House,
Opposite Elephant Cement House Assbifi Road,
CBD Alausa, Ikeja,
Lagos State.
Nigeria.
Tel: +2348023022110
Email: oluropo.olajugba@lordsfield.com