Comparative Analysis of Short, Medium and Long Baseline Processing in the Precision of GNSS Positioning

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Key words: Baseline, Precision, GNSS, Positioning, CORS

SUMMARY

The science of positioning has revolutionized with the advent of high precision instruments targeted to improving the achievable accuracy in positioning. GPS has presently evolved into GNSS, with the GNSS receivers having the capability of tracking different satellite constellations. Active CORS have emerged replacing the former passive stations. These innovations in the science of satellite positioning however, have not undermined the importance of baseline processing in satellite based positioning system. This paper thus, presents a comparative analysis and the significance of short, medium and long baseline processing in the precision of GNSS positioning. Satellite observations were acquired on 19 control points within university of Lagos using both the passive and active (CORS) station principles in Post Processing GNSS positioning data at differential mode. The short baselines have maximum length not exceeding 1.5km from the control points to a base station in university of Lagos, the medium baselines have range not exceeding 12km from the control points to a CORS located at the Lagos state Surveyor General's Office, Nigeria, while the long baselines have range not exceeding 107km from the control points to another CORS located in Cotonuo, Benin Republic. After post processing operation using GNSS baseline processing software, the horizontal and vertical precision for all stations during the short, medium and long baseline scenario were obtained. The results were statistically analysed using ANOVA One Way at 0.05 significant level i.e. 95% confidence interval comparing the average vertical and horizontal precision of all stations during the three baseline observation scenario and subsequently Scheffe test was conducted on the ANOVA results. The statistical results shows no significant difference between the level of precision obtained by the baseline processing involving the CORS at 12km and the Base receivers at 1.5km but there exist a significant difference between the 107km CORS baseline processing and the 12km as well as the 1.5km baselines. The short baselines were found to have the highest achievable processing precision while the long baselines have the least. The study shows that the longer the baselines the lower the processing precision even with CORS. This however, does not negate the reliability of the long baseline result but defines the level of precision and accuracy achievable when compared with other baseline length.

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1. INTRODUCTION

The emergence of Global Positioning System (GPS) has revolutionized the conventional method of position determination and the science of navigation. GPS is a satellite positioning system based on one-way ranging in which the measurement of travel time of a signal from transmitter to receiver is achieved by the application of separate clocks; the transmitter (GPS satellites in space) and the receiver clock (GPS receivers on the earth's surface). The two clocks must be properly synchronized as a deviation in 1nanosecond is equivalent to 30cm in distance (Rizos, 1999).

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 might not be 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 both in PPP and differential positioning. The baselines spans from short to long ranges with various error compensation and correction applied to longer baseline to achieve desired precision and accuracy with the use of various commercial GNSS data processing software.

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).

Recent development in GNSS has led to a paradigm shift from passive network of geodetic controls to active CORS. The active stations are continuously developed into a network system capable of reducing the number of stations over a coverage area by extending baseline length and at the same time improving the accuracy of processing the baselines between the reference stations and the rovers. This could be achieved either from a networked GNSS stations where all stations are linked to a central control station for data correction and modelling or the most advanced technique nowadays based on the VRS network concept (Retscher, 2002).

Looking at the recent development in GNSS and CORS the study is aimed at carrying out a comparative analysis of the attainable precision in processing long, medium and short baselines in GNSS positioning. This was achieved by acquiring positional data using a GNSS receiver on 19 selected control stations within University of Lagos Nigeria, processing the observations with respect to a mounted conventional base station within the university forming the short baseline, a CORS in Lagos State located in the Lagos State Surveyor General's office over 10km away from the university (forming the medium baseline) and a CORS in Cotonou, Benin Republic over 100km away (forming the long baseline). The results were subsequently analysed and presented.

2. STUDY AREA

The research was carried out on some selected control points within University of Lagos, Lagos State Nigeria with reference made to a conventional base station on a first order control within the campus, a CORS located at the Office of the Surveyor General of Lagos State and a CORS located in Littoral State of Benin Republic, Cotonuo. Nigeria lies between Longitudes 30 and 140 East of the Greenwich meridian and Latitude 40 and 140 North of the equator. Lagos State in Nigeria lies between Longitude 2º 45'E to 4º 20'E and Latitude 6º 2'N to 6º 27'N. Benin Republic lies between Longitude 1º E to 3º 40' E and Latitude 6º 30' N to 12º 30' N while Cotonuo In Benin republic lies between Longitude 2º 26' E and Latitude 6º 22'N

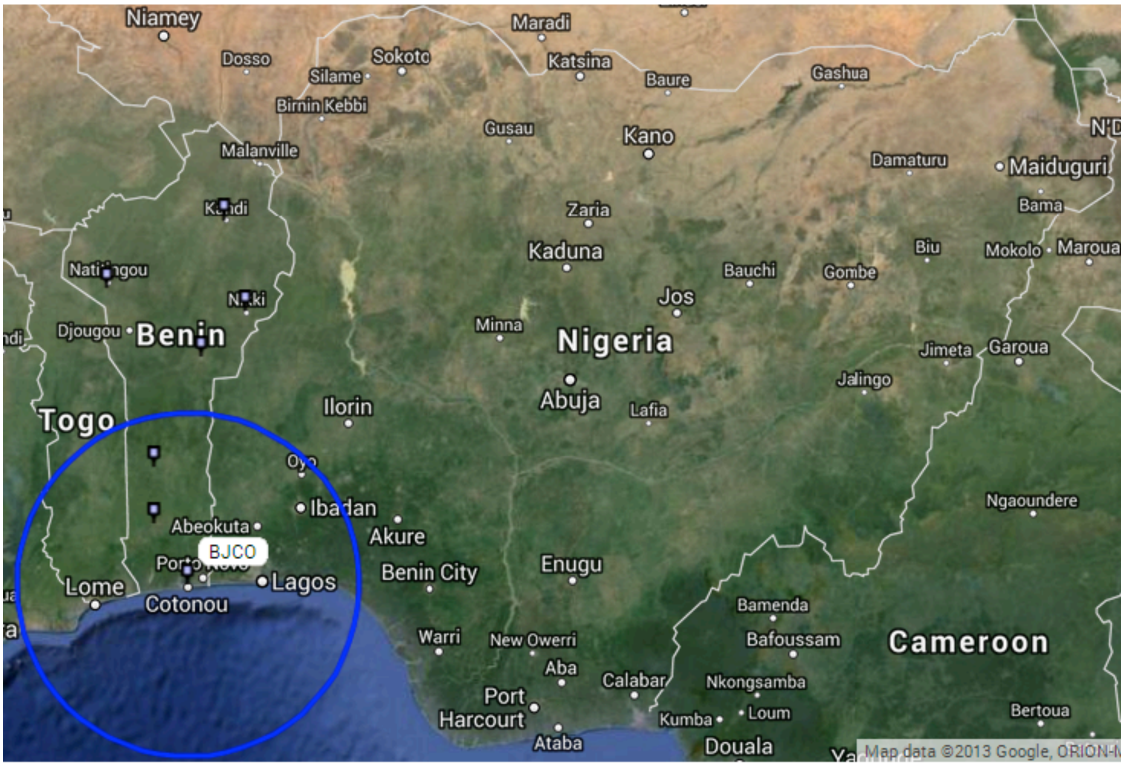

Figure1: Imagery showing the map of Nigeria and Benin republic with the Location of Cotonou, Benin Republic and Lagos, Nigeria. (Source:Google earth)

3. INSTRUMENTATION

Trimble R5 GNSS receiver was used in acquiring the satellite ephemeris at the selected control stations within University of Lagos. The data acquired was processed with respect to data acquired by another Trimble R5 GNSS receiver located at XST347 base station to form the short baseline. Simultaneous observation data set were also downloaded from the Lagos CORS and the Cotonou CORS for medium and long baseline observation respectively.

The Trimble R5 GNSS receiver utilizes a Zephyr antenna and has the following measurement features; Trimble R-Track technology, Advanced Trimble Maxwell TM Custom Survey GNSS Chip, High precision multiple correlator for GNSS pseudo range measurements, Unfiltered, unsmoothed pseudo range measurements data for low noise, low multipath error, low time domain correlation and high dynamic response, Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth, Signal-to-Noise ratios reported in dB-Hz, Proven Trimble low elevation tracking technology, 72 Channels : – **GPS** L1 C/A Code, L2C, L1/L2 Full Cycle Carrier, – **GLONASS** L1 C/A Code, L1 P Code, L2 P Code, L1/L2 Full Cycle Carrier and 4 SBAS WAAS/EGNOS Channels. It has a static and fast static horizontal RMS of 3mm + 1ppm and vertical RMS of 3.5mm + 0.4 ppm (Trimble R5 Datasheet).

The Lagos CORS is a single Continuously Operating Reference Station established by the lagos state government under the control and management of the office of the Surveyor General of Lagos State. It is a Leica CORS infrastructure designed with the leica Spider software.

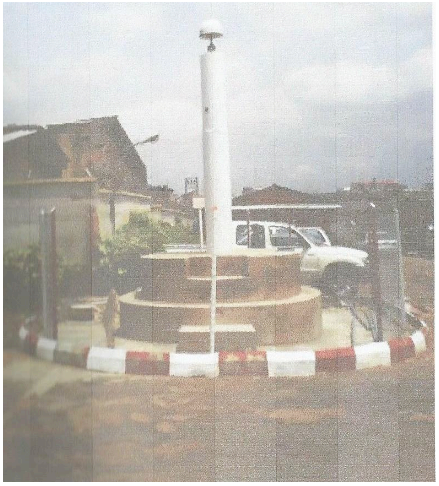

Figure 2: Lagos CORS (LAG01) Source: Authors' Research

The Cotonou CORS in Littoral State of Benin Republic is one of the CORS of the International GNSS Service. It has BJCO as its four character ID and stands on a monument 3.9m tall. It utilizes a Trimble NET R5 receiver type and has a GNSS capability of tracking both GPS and GLONASS satellites including other satellite constellations. It is a Trimble CORS infrastructure.

Figure 3: Cotonuo CORS (BJCO) Source: IGS

4. DATA COLLECTION AND PROCESSING

The process of Fast Static survey was done uninterruptedly for a minimum period of 30 minutes for each session. The base station 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.

As stated earlier in the previous section concerning the 24/7 operation of the LAG01 and BJCO CORS, it becomes imperative to note the time and date of observation of all rover stations for successful download of simultaneous CORS observation at the CORS control center. The simultaneous observation for the LAG01 CORS were downloaded at the control center located at the Office of the Surveyor General of Lagos state while the simultaneous observation of the BJCO CORS were downloaded via the internet with respect to the time session of observation. The BJCO CORS data being a data from the International GNSS service is available via the internet and accessible directly for download linking the rover stations using appropriate software. The data of CORS were downloaded in RINEX format.
Trimble Business Center was then used in processing all observations involving the three baselines.

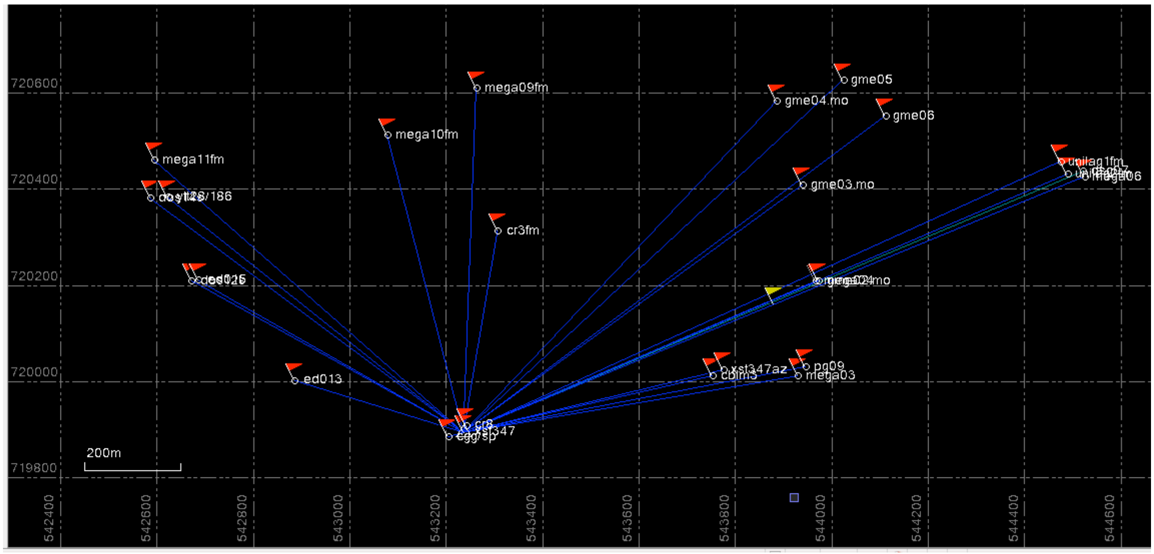

Figure 4: Showing GNSS Processed Short baselines (Source: Authors' Research)

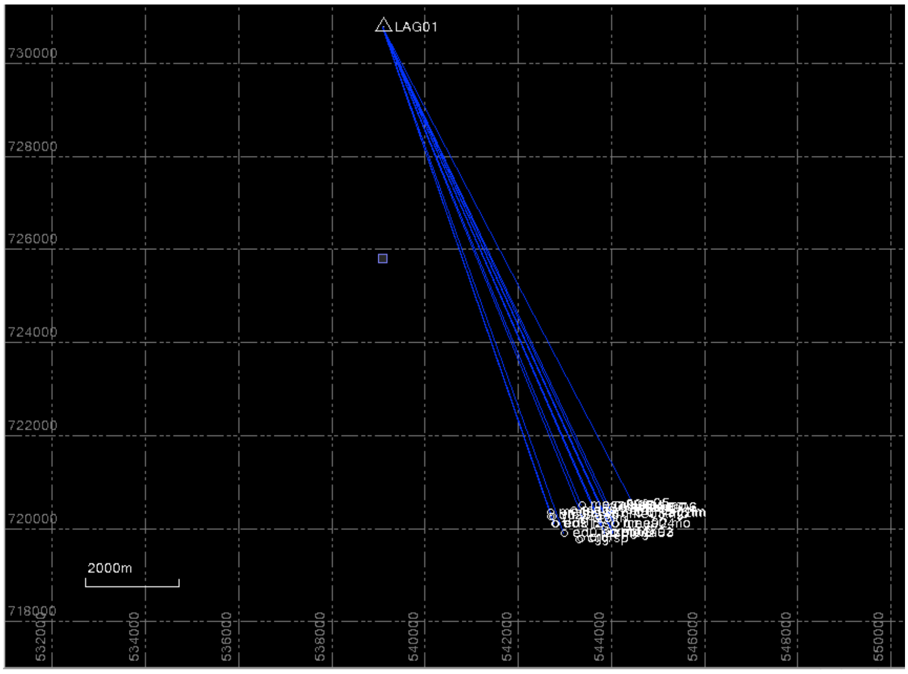

Figure 5: Showing GNSS Processed Medium baselines (Source: Authors' Research)

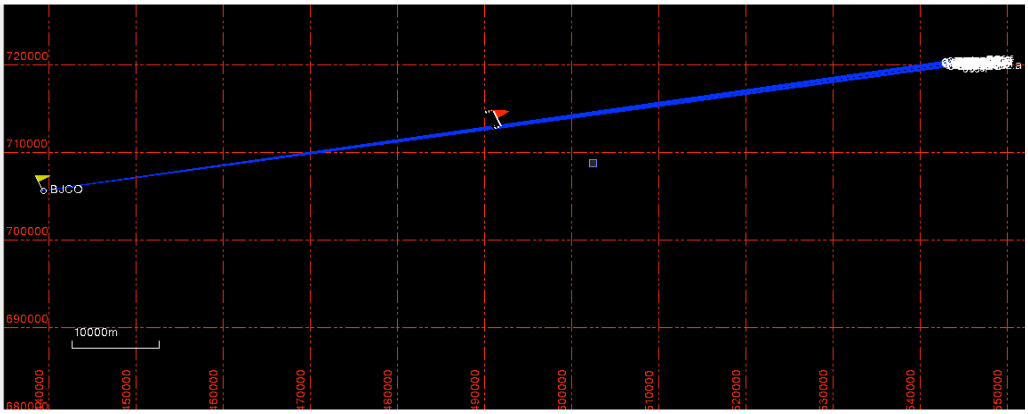

Figure 6: Showing GNSS Processed Long baselines (Source: Authors' Research)

4. RESULTS AND ANALYSIS

4.1 Results

Table 1: Result of GNSS Short Baselines Processing of Selected Stations with Horizontal and Vertical Precision

Stations	Easting (m)	Northing (m)	Height (m)	Horizontal Precision (m)	Vertical Precision (m)
Cr 8	543240.659	719908.825	6.247	0.003	0.005
Cblm 3	543750.878	720011.466	7.448	0.002	0.003
XST347az	543773.417	720023.868	8.157	0.003	0.005
Mega 03	543928.957	720011.221	9.848	0.008	0.014
PG 09	543944.031	720030.444	9.814	0.004	0.007
ED 013	542884.766	720001.874	7.855	0.002	0.002
ED 015	542684.951	720210.028	8.715	0.005	0.008
DOS 12S	542670.865	720209.530	8.622	0.011	0.018
DOS 14S	542584.668	720380.971	8.640	0.003	0.005
Ytt 28/186	542621.444	720382.246	8.847	0.009	0.008
Gme 02	543971.894	720208.622	8.076	0.005	0.009
Gme 03	543938.78	720408.336	8.306	0.006	0.012
Cr3 f	543306.243	720312.627	6.515	0.013	0.022
Mega 09	543261.651	720608.475	8.442	0.005	0.009
Mega 10	543077.216	720510.877	8.763	0.007	0.007
Mega 11	542592.889	720460.042	7.663	0.016	0.019
Mega 06	544435.929	720542.61	1.558	0.062	0.132
Unilag 1	544473.004	720456.463	3.962	0.006	0.014
Unilag 2	544488.197	720430.507	3.786	0.06	0.01

Table 2: Result of GNSS Medium Baselines Processing of Selected Stations with Horizontal and Vertical Precision

Stations	Eastings (m)	Northing (m)	Height (m)	Horizontal Precision (m)	Vertical Precision (m)
Cr 8	543330.824	719790.447	6.569	0.007	0.012
Cblm 3	543841.038	719893.072	7.278	0.008	0.011
XST347az	543863.577	719905.477	7.983	0.008	0.014
Mega 03	544019.114	719892.834	9.667	0.007	0.014
PG 09	544034.197	719912.058	9.616	0.023	0.033
ED 013	542974.923	719883.486	7.862	0.008	0.01
ED 015	542775.055	720091.504	8.626	0.013	0.022
DOS 12S	542761.01	720091.148	8.619	0.011	0.023
DOS 14S	544062.056	720090.234	8.084	0.009	0.015
Ytt 28/186	542711.611	720263.866	8.63	0.015	0.031
Gme 02	544062.056	720090.234	8.084	0.011	0.035
Gme 03	544028.938	720289.958	8.31	0.015	0.033
Cr3 f	543396.388	720194.26	6.541	0.007	0.022
Mega 09	543351.809	720490.111	8.459	0.007	0.018
Mega 10	543167.367	720392.512	8.72	0.009	0.022
Mega 11	542683.089	720341.713	7.555	0.013	0.038
Mega 06	544526.948	720424.043	5.857	0.183	0.288
Unilag 1	544563.151	720338.086	3.886	0.011	0.025
Unilag 2	544578.369	720312.131	3.563	0.026	0.076

Table 3: Result of GNSS Long Baselines Processing of Selected Stations with Horizontal and Vertical Precision

Stations	Eastings (m)	Northing (m)	Height (m)	Horizontal Precision (m)	Vertical Precision (m)
Cr 8	543329.842	719789.529	5.911	0.289	0.264
Cblm 3	543840.049	719892.159	6.487	0.242	0.276
XST347az	543862.474	719904.605	5.307	0.373	0.155
Mega 03	544018.315	719892.065	9.048	0.361	0.318
PG 09	544033.377	719911.232	9.315	0.407	0.52
ED 013	542973.912	719882.636	6.826	0.284	0.124
ED 015	542773.782	720090.569	8.358	0.311	0.425
DOS 12S	542759.58	720090.184	7.657	0.39	0.338
DOS 14S	542673.765	720261.667	7.698	0.173	0.096
Ytt 28/186	542710.519	720262.978	8.012	0.346	0.167
Gme 02	544061.121	720089.393	7.359	0.459	0.487
Gme 03	544027.785	720289.102	7.478	0.338	0.227
Cr3 f	543395.358	720193.368	3.864	0.289	0.163
Mega 09	543350.816	720489.253	7.762	0.246	0.241
Mega 10	543166.31	720391.624	8.065	0.199	0.136
Mega 11	542681.875	720340.629	7.192	0.447	0.456
Mega 06	544525.54	720423.329	2.161	0.419	0.496
Unilag 1	544562.093	720337.209	2.971	0.247	0.153
Unilag 2	544577.414	720311.303	2.835	0.207	0.182

4.2 Statistical Analysis of Results

Table 4: One Way ANOVA Result Summary

		Sum of Squares	**df**	**Mean Square**	**F**	**P(<F)**
Horizontal Precision (m)	Between Groups	1.147	2	.574	186.366	.000
	Within Groups	.166	54	.003		
	Total	1.314	56			
Vertical precision (m)	Between Groups	.780	2	.390	47.953	.000
	Within Groups	.439	54	.008		
	Total	1.218	56			

H_O: No differences between the means of the 3 groups
H_A: At least one of the means is not the same as other means (α = 0.05)

REJECT H_O at α = 0.05
At least one of the means is not the same as other means

Table 5: Scheffé Test Results

	SAMPLE TO SAMPLE		**F**	**P(>F)**	**COMMENTS @ (α = 0.05)**
Horizontal Precision (m)	Short Baseline	Medium baseline	0.11	0.90	
	Short Baseline	Long Baseline	143.65	0.00	Short Baseline Mean < Long Baseline Mean
	Medium Baseline	Long Baseline	135.78	0.00	Medium Baseline Mean < Long Baseline Mean
Vertical Precision (m)	Short Baseline	Medium baseline	0.30	0.74	
	Short Baseline	Long Baseline	39.11	0.00	Short Baseline Mean < Long Baseline Mean
	Medium Baseline	Long Baseline	32.52	0.00	Medium Baseline Mean < Long Baseline Mean

4.2 Graphical Analysis

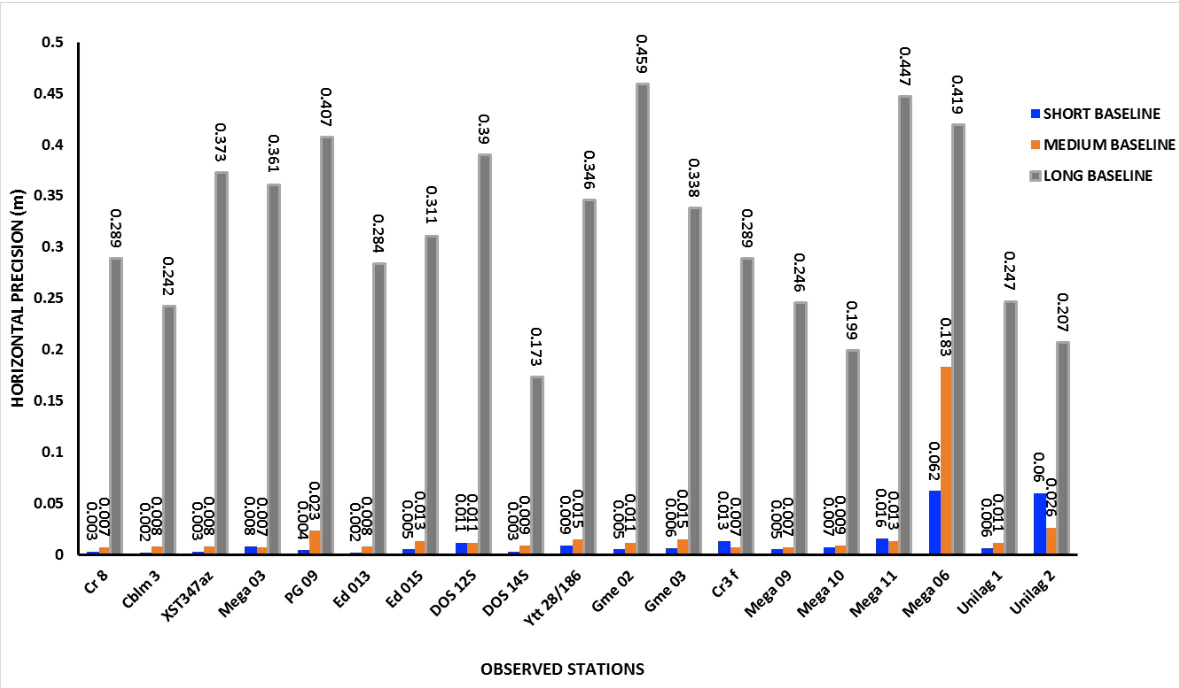

Figure 7: Graphical comparison of Horizontal Precision at the Short, Medium and Long Baseline Observations

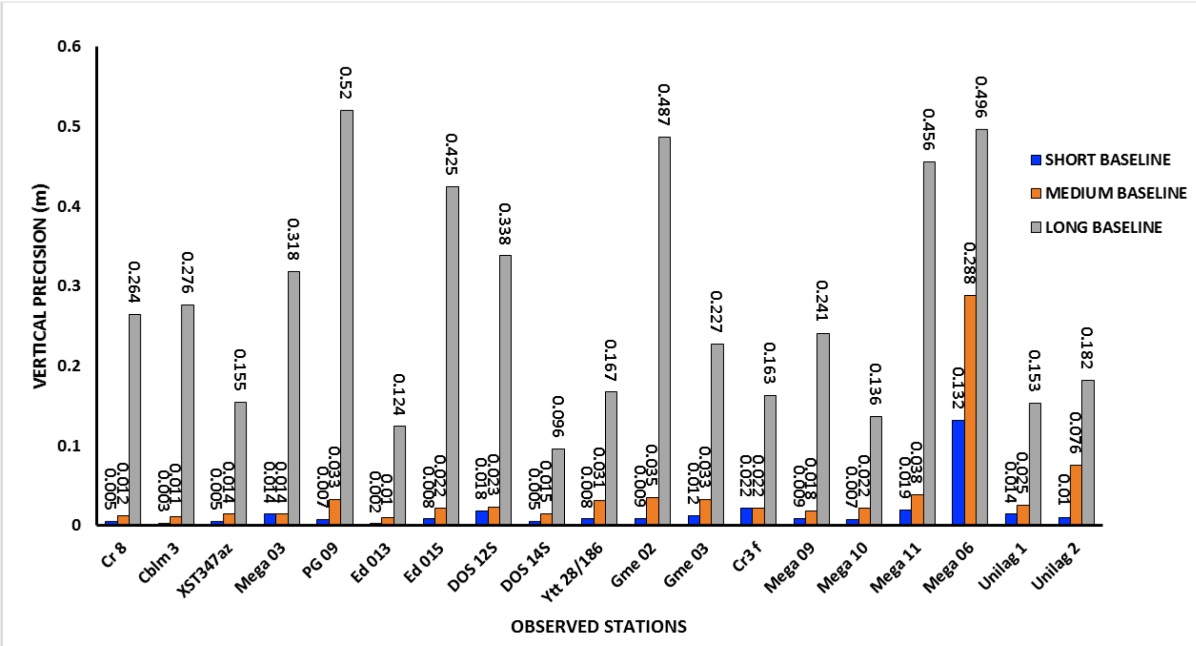

Figure 8: Graphical comparison of Vertical Precision at the Short, Medium and Long Baseline Observations

4.3 Discussions

All foregoing results presentations were obtained from observations, processing and analysis of short, medium and long GNSS baselines. These are constructively presented in tabular and graphical forms for easy interpretations.

Tables 1, 2 and 3 show the results of the spatial coordinates as well as resulting horizontal and vertical precision for the short, medium and long baselines GNSS processing of the observed stations 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. A graphical comparison of the horizontal and vertical precision for the three baseline scenarios were illustrated in figures 7 and 8 respectively. In both charts it can be observed that, observations involving the long baselines have the least level of accuracy i.e. the highest precision value as compared to the short and medium baseline observations in both the horizontal and vertical precision. While for the short and medium baselines, there is predominantly higher level of attainable accuracy in the short baseline. However there exist some stations having equal and higher accuracy in the medium baseline processing compared to the short baselines; such as, ***Dos12S*** station, having equal horizontal precision for both the short and medium baselines and ***Mega03, Cr3f, Mega 11*** *and* ***Unilag 2*** stations, having horizontal precision for the medium baseline higher than the short baseline. Also, in figure 8 it can be observed that ***Mega03*** and ***Cr3f*** have equal vertical precision for both the medium and short baselines.

Table 4 shows the results of One Way ANOVA statistical test performed on the horizontal precision and vertical precision results for the short, medium and long baselines. The test was conducted at 95% confidence interval; that is, 0.05 significant level. The null hypothesis states that these is no significant difference between the average mean precision on the three baseline processing scenarios while the alternative states otherwise. The end results of the test indicates that there exist significant difference in at least one of the data set compared to another. This existing difference requires a further testing to ascertain where the differences lie. This further Post-Hoc test was conducted using Scheffé statistical testing.

The results of the Scheffé test indicates that these is no significant difference in the results of the short and medium baseline but there is a significant difference in the results of the short and long baseline and the results of the medium and long baseline. The Scheffé test was also conducted at 0.05 significant level. The summary of the Scheffé results can be clearly seen in table 5.

5. CONCLUSION

The research has shown that GNSS baseline processing is dependent on the baseline length. The longer the baseline length the lower the attainable precision. The horizontal and vertical precision of all the observed stations varies as the baseline length changes. The variation is not only dependent on static conventional base station but also CORS. The medium and Long baseline of this research were conducted with CORS and results indicated that the length of baseline between the CORS and the observed stations also affect the precision and standard error in relative positioning.

The statistical tests indicated the progressive error propagation in positional accuracy as the medium and short baseline results show no significant difference but they both statistically differ from the long baselines. All graphical illustrations has indicated the inherent and prevalent variations in error propagation with respect to the length of the processing baselines. The research has thus, justified the importance of understanding the concept of baseline processing in GNSS positioning as it has a high effect in the achievable positional accuracy both for conventional base stations and for CORS.

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BIOGRAPHICAL NOTES

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