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Degradation of GNSS Accuracy by Multipath and Tree Canopy Distortions in a School Environment

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ABSTRACT - ***Accurate position determination with GNSS technology requires unimpeded view of the sky. It has however been noticed that control stations established with GNSS technique for surveying/research projects no longer yield the desired accuracy after some years. This could be as a result of environmental features (buildings, fences, trees, etc) sprouting around them due to infrastructural development and urbanization. This paper investigates the extent of degradation of accuracy at fifteen such stations located within a school environment. The study was done by comparing GNSS fixes of those stations with their corresponding positions determined in a total station (electronic tacheometer) survey. The latter was used as study control because it is not affected by the environmental features and factors monitored. The study showed that some of the stations are no longer suitable for the GNSS technique (GDOP is too high (171.6)); while for others, their GNSS-derived positions differed from those of total station by as much as 5.7m. All the controls were therefore reclassified in accordance with national and international accuracy standards. We also recommend that once in a while such checks and reclassification should be done for existing controls.***

Keywords--- GNSS accuracy, multipath, tree canopy, environment, reclassification

1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) is a generic name given to navigation systems which use satellites to give precise positional information day or night in most difficult weather and terrain conditions. With the affordability, ease of use and its accuracy, GNSS provides fundamental data required to meet the needs not only of the geodesist and the geoscientist, but also of professional GNSS users in areas of surveying, mapping and navigation.

There are however, many questions regarding the capabilities and limitations of GNSS technology in urban setting where uncertainties from tree canopy interference, electric wire/cable interference, and multipath effects are expected. [14] and [10] stipulated that there are several sources of error that degrade the GNSS position and the accuracy of a GNSS receiver measurement which include delays caused by the ionosphere and the troposphere. Objects near a receiver antenna, such as trees or buildings, can reflect GNSS signals and result in one or more secondary propagation paths [2] and [11]. These secondary path signals can interfere with the signal that reaches the receiver directly from the satellite, distorting its amplitude and phase significantly [16].

[1] recognises the factors that affect GNSS positioning and hence recommends that areas with strong electromagnetic frequencies and reflective surfaces should be avoided as they induce the effects of multipath and also cause cycle slips. Cycle slips and multipath are undesirable in a satellite measurement because they affect the accuracy of a point determined by GPS & GLONASS signals. Multipath affects both pseudo range and carrier phase measurements [13]. Multipath creates inaccurate measurements by causing the receiver to measure a longer or shorter pseudo range. Canopy cover may interfere with satellite signal reception and make it difficult to make reliable measurements. The combined effects of tree canopy and multipath degrade the performance of all GPS receivers. The users are limited to a narrow view of the sky in a tree canopy environment resulting in the GNSS receiver to be locked to only high elevation satellites. Satellite constellations also have a large effect on the quality of the data collected in forested environments such as data bias. Constantly changing constellations result in inconsistent and poor relative data accuracy. Satellite availability degrades the accuracy of the positions by deliberately introducing errors into the satellite navigational data and clock. Additional errors in the satellite clock, satellite ephemeris, receiver clock, and atmospheric delays further degrade accuracy. Satellite geometry also affects accuracy, and position dilution of precision (PDOP) is a numerical representation of the geometry of the satellite constellation. The lower the PDOP, the higher the expected positional accuracy [15].The effect of signal obstruction is to convey an increase in PDOP. As PDOP is related to the satellite geometry and number of satellites logged, a lower PDOP is a unit-less measure indicating the quality of satellite geometry. When the satellites are spread around the sky, the PDOP value is low and the computed position is more accurate. In the case where satellites are grouped closely, the PDOP is high and the positions are less accurate.

With increased use of GNSS in urban and tree canopy environment setting, there is a need to understand the accuracies achievable in such landscapes. Most previous GNSS evaluations have been performed under "clear sky" conditions, where views to satellites are unobstructed. [3] has however, studied the effects of terrain, tree canopy, and position dilution of precision (PDOP) on GNSS accuracy. They found out that the positional accuracy was higher for open sites compared to sub-canopy sites. So, position accuracy is often degraded in difficult terrain conditions, and in most cases may not meet accuracy standards and hence, requires resurveying. Also modern GNSS technologies have improved based on its advanced tracking. But in spite of this advanced tracking capability; the signals are noisier, weakened and more likely to be subject to multipath and diffraction. Despite the quality indicators showing good solutions, positions may not be accurate.

In order to overcome this situation, [7] provided techniques used to mitigate or eliminate multipath errors in positioning. Also, [8], [6], [9], [10] and [4] suggest that the surveyors are required to check out the GPS results using a total station. In this case, terrestrial survey would help productivity in difficult terrain conditions and be carried out to obtain an independent result of the position for assessing the accuracy of the GPS results in forest and tree canopy environment since total station is not affected by either canopy or multipath. The foregoing implies that existing high accuracy GNSS controls could later be degraded by environmental features (buildings, fences, trees, etc) which later come into existence around them. In the school environment under study, there are many of such controls. The authors have therefore used a total station survey to estimate the amount of degradation that has occurred on fifteen such controls and reclassified them in accordance with national (Nigerian) and international (USA) accuracy standards.

2. STUDY ENVIRONMENT

The study environment is the University of Nigeria Enugu Campus (UNEC). It is one of the campuses of the University of Nigeria, Nsukka and is located between longitudes 7°29'48.73"E and 7°30'14.48"E and latitudes 6°25'37.28"N and 6°25'54.81"N. UNEC has a total land mass of 1,219,072.576 square metres or 121.907258 Hectares in area, and having total perimeter of 5417.968m. UNEC has five faculties which consist of, in no particular order or hierarchy, the College of Medicine, faculty of Law, faculty of Business Administration and Management, faculty of Health Technology and faculty of Environmental Studies. It also has an administrative block, security department, works department, student hostels, soccer stadium and other recreational facilities.

Figure 1: Map of Nigeria showing Enugu State

The study area is a semi-urban setting characterised by local environmental features such as trees, buildings, tall fences, electric poles and high tension electric lines (Fig. 2). These features are suspected to limit the accuracy in GNSS positioning by factors such as multipath and tree canopy.

Figure 2: Aerial view of the study area (part of UNEC) with the 15 controls

The fifteen stations used for the study and the environmental features surrounding them are shown in Table 1 and Figs 1 to 6. At the time some of the controls were established, those obstructing features were non-existent. A good example is G2 station (Fig 3) which was established in an open field and served as an important national geodetic control for high standard surveys and researches but recently, a two storey building was erected within six metres of it.

Table 1: List of stations with their respective environmental features

No	**Stations**	**Environmental features**	**Error sources**
1	N102	Flowers and asphalt road (open sky)	None
2	N103	Asphalt road (open sky)	None
3	G2	Building and metallic wire	Multipath
4	UNEC 7	Building	Multipath
5	UNEC 8	Tree canopy	Cycle slips
6	DPR 722	Building, asphalt road, tree canopy and wire fence/hedge	Cycle slips, Multipath
7	DPR611 (03)	Electric wire	Electric interference
8	DPR 772	Tree canopy	Cycle slips
9	N106	Building and flowers	Multipath
10	DPR611 (13)	Asphalt road (open sky)	None
11	SGP1	Asphalt road and grasses	Multipath
12	DPR611 (07)	Building	Multipath
13	DPR611 (08)	Tree canopy and Building	Cycle slips and Multipath
14	UNEC 15	Tree canopy and Building	Cycle slips and Multipath
15	UNEC 10	Tree canopy	Cycle slips

Figure 3: G2 environment

Figure 4: DPR611 (03) environment

Figure 5: DPR 722 environment

Figure 6: UNEC 15 environment

3. METHOD OF STUDY

In this study, the evaluation of the degradation involved static GNSS and total station traverse field observations on fifteen existing control stations. Twelve of the stations were chosen because they were located where they could be affected by tree canopy, multipath, electricity interference or their combination; while the remaining three stations were located in open field where they may not be affected by any distortions (Table 1). GNSS (Leica 1200+ DGPS) and terrestrial (Leica TCA 1300+ Total station) were used for the field work. Two hours static GNSS observations were taken at each station and later processed with Leica Geo Office (LGO) software.

Parameters used for assessing degradation include dilution of precision (GDOP, PDOP) and precision of GNSS positioning (Table 2) as well as the external consistencies derived from the differences between coordinates obtained from GNSS and Total station techniques (Table 3).

4. RESULTS AND DISCUSSIONS

4.1 Satellite Geometry Effect

GNSS data processing with Leica Geo Office (LGO) software yielded standard deviations in the stations' easting and northing coordinates as well as "position + height quality" for all the stations (Table 2). The minimum and maximum values of different types of dilution of precision (Geometric DOP (GDOP), Position DOP (PDOP)) are also shown. These indicate the effects of the features surrounding the stations on the geometry of the satellites used for position and height quality determination.

It can be seen also from Table 2 that DPR 722 station recorded the highest DOP values (GDOP=171.6; PDOP=130.6) and corresponding low quality "position + height" of 1.990m. Table 1 and Fig. 5 show that the station is surrounded by tree canopies, wire fence/hedge and buildings. It should however, be noticed also that some stations with low DOP had poor "position + height" quality and high standard deviations in their easting and northing coordinates (examples: UNEC 15, UNEC10, etc). This could indicate that DOP may not be the only source of error but that errors may have arisen from other sources such as signal attenuation due to tree canopy and multipath effects.

Table 2: Station Position and height quality by GNSS technique

STATIONS	Posn + Hgt Qlty (m)	STD. DEV. E(m)	STD. DEV. N(m)	GDOP		PDOP	
				MIN	MAX	MIN	MAX
N102	0.3322	0.0076	0.0113	1.6	2.6	1.4	2
N103	0.3804	0.0096	0.0172	1.6	2.5	1.3	2
G2	0.6077	0.0054	0.0098	1.7	5.3	1.4	4.3
UNEC7	0.7550	0.0097	0.0080	1.5	4.2	1.3	3.7
UNEC8	0.5815	0.0067	0.0118	1.7	2.5	1.4	2.1
DPR 722	1.9903	0.0119	0.0116	2	171.6	1.7	130.6
DPR611 (03)	0.6430	0.0058	0.0058	1.7	2.2	1.5	1.8
DPR 772	0.5654	0.0046	0.0080	1.8	2.9	1.5	2.4
N106	0.4453	0.0036	0.0065	1.4	3.7	1.2	1.9
DPR611 (13)	0.3844	0.0052	0.0039	1.8	2.4	1.5	2
SGP1	0.5907	0.0029	0.0060	1.6	2.5	1.4	2.1
DPR611 (07)	0.9296	0.0081	0.0088	1.9	3.9	1.5	3.1
DPR611 (08)	1.0803	0.0260	0.3290	1.9	7.4	1.6	5.8
UNEC 15	1.1400	0.0088	0.0052	1.7	4.3	1.4	3.6
UNEC 10	1.0349	0.0059	0.0104	1.6	5	1.3	4

4.2 External Consistency

Differences between positions determined by GNSS and Total station (Electronic Tacheometer) techniques are displayed in Table 3 and Fig. 7. These results show that stations NI02, NI03 and DPR 611(13) which are located in an open field (under open sky) had discrepancies below 0.006m (DPR611 (03) with discrepancy of 0.048m is in an open field but under a high tension electric line) while the stations surrounded by trees, fences and other features had large discrepancies exceeding 1.0 metre in most cases (examples are G2, UNEC8, DPR 722 etc.).

Table 3: Difference of DGPS and Total station coordinates

S/ N	**Station**	**DGPS**		**TOTAL STATION**		**DIFFERENCE**		**Total 2D Diff (m)**
		Easting (m)	**Northing (m)**	**Easting (m)**	**Northing (m)**	**ΔE (m)**	**ΔN (m)**	
1	NIO2	334531.788	710471.253	334531.789	710471.252	-0.001	0.001	0.001
2	NIO3	334650.201	710615.216	334650.201	710615.215	0.000	0.001	0.001
3	G2	334743.955	710471.450	334744.825	710473.087	-0.870	-1.637	1.854
4	UNEC8	334768.085	710533.213	334766.162	710531.774	1.923	1.439	2.402
5	UNEC7	335027.461	710347.223	335028.075	710346.022	-0.614	1.201	1.349
6	DPR 722	334955.067	710179.881	334959.373	710176.107	-4.306	3.774	5.726
7	DPR611 (03)	334899.079	710122.236	334899.071	710122.189	0.008	0.047	0.048
8	NIO6	335276.211	710570.222	335275.855	710572.022	0.356	-1.800	1.835
9	DPR 772	334770.363	710242.712	334768.028	710241.561	2.335	1.151	2.603
10	DPR 611(13)	334828.181	710305.089	334828.186	710305.090	-0.005	-0.001	0.005
11	SGP 1	334784.718	710397.410	334784.127	710397.006	0.591	0.404	0.716
12	DPR 611(07)	334776.983	710375.568	334773.077	710377.205	3.906	-1.637	4.235
13	DPR 611(08)	334763.071	710342.113	334765.480	710340.142	-2.409	1.971	3.113
14	UNEC 15	334664.282	710381.166	334662.845	710383.063	1.437	-1.897	2.389
15	UNEC 10	334694.141	710439.565	334693.408	710441.705	0.733	-2.140	2.262

Where **TOTAL 2D DIFF.** = $\sqrt{\Delta \boldsymbol{E}^2 + \Delta \boldsymbol{N}^2}$

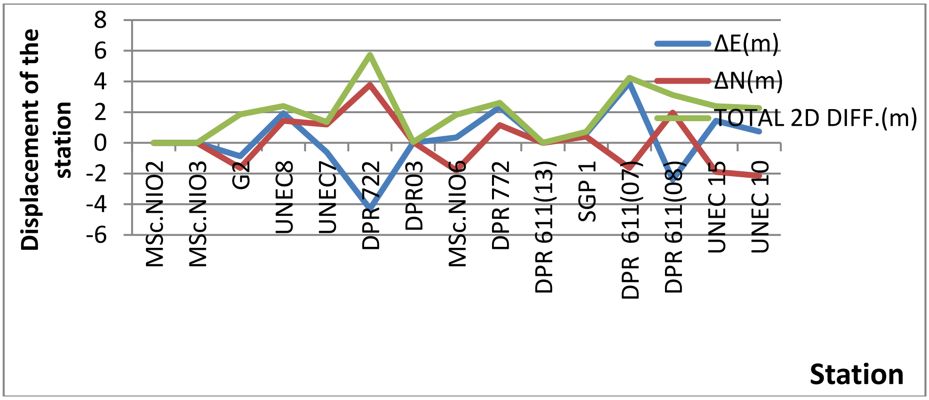

Figure 7: Graph showing the magnitude of positional degradation on the stations

4.3 Reclassification of Controls

To determine the suitability of the fifteen controls for various orders of GNSS relative positioning, we reclassified them based on the 1998 and 1984 accuracy standards of the Federal Geodetic Control Subcommittee of the United States of America (FGCS, USA) (Tables 4 and 5) [5]. The 2007 accuracy standards of the Surveyors Council of Nigeria (SURCON) was also applied (Table5) [12].

Table 4: 1998 FGCS (USA) accuracy standards

S/N	Accuracy Classification	95% (2σ) confidence (metres)
1	1mm	0.001
2	2mm	0.002
3	5mm	0.005
4	1cm	0.010
5	2cm	0.020
6	5cm	0.050
7	1dm	0.100
8	2dm	0.200
9	5dm	0.500
10	1m	1.000
11	2m	2.000
12	5m	5.000
13	10m	10.000

Table 5: 1984 FGCS and 2007 SURCON Accuracy Standards for GPS Relative Accuracy

GPS Order	Relative Accuracy	Traditional Survey Order and Class	
		FGCS (USA)	SURCON (Nigeria)
Order AA	1/100,000,000		
Order A	1/10,000,000		
Order B	1/1,000,000		Zero Order
Order C-I	1/100,000	1st Order	1st Order
Order C -2-I	1/50,000	2nd Order Class1	2nd Order
Order C-2-II	1/20,000	2nd Order Class2	3rd Order
Order C-3	1/10,000	3rd Order Class 1	4th Order
	1/5,000	3rd Order Class 2	“

Their relative accuracies, R were computed from:

$$R = \frac{e}{D}$$

Where,

e = error in GNSS-derived position relative to Total Station position
D = distance of rover station from base station

In this, we assumed a scenario where the GNSS base receiver is setup at NI02 (in the open field) while the rover receiver is on each of the other fourteen controls. The results are shown in Table 6. The value for Station G2 is illustrated in Fig 8.

Table 6: Relative accuracies and orders of radial baselines from NI02

From	To	ΔE (m)	ΔN (m)	Distance, D (m)	2D Difference (Error, e) (m)	Relative Accuracy ($\frac{e}{D}$)	Order
NI02	NI03	118.413	143.963	186.405	0.001	1/186,405	1st Order
	G2	212.167	0.197	212.167	1.854	1/114	
	UNEC8	236.297	61.960	244.285	2.402	1/102	
	UNEC7	495.673	-124.030	510.955	1.349	1/379	
	DPR722	423.279	-291.372	513.870	5.726	1/90	
	DPR03	367.291	-349.017	506.671	0.048	1/10,556	3rd Order class 1
	NI06	744.423	98.969	750.973	1.835	1/409	
	DPR772	238.575	-228.541	330.377	2.603	1/127	
	DPR611(13)	296.393	-166.164	339.793	0.005	1/67,959	2nd Order Class 1
	SGP1	252.930	-73.843	263.489	0.716	1/368	
	DPR611(7)	245.195	-95.685	263.204	4.235	1/62	
	DPR611(8)	231.283	-129.140	264.894	3.113	1/85	
	UNEC15	132.494	-90.087	160.220	2.389	1/67	
	UNEC10	162.353	-31.688	165.417	2.262	1/73	

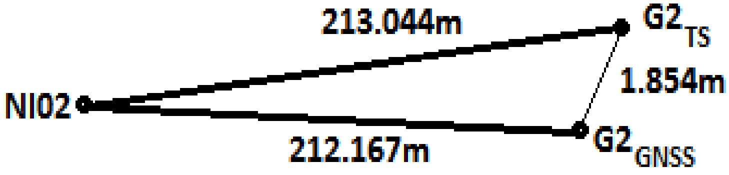

Figure 8: Displacement of the G2 control by environmental factors

5. CONCLUSION AND RECOMMENDATIONS

From Table 6, it can be seen that only four stations (NI02, NI03, DPR611 (03), and DPR611(13)) are still suitable for GNSS positioning. Of interest is the fact that all four are in the open field with minimal disturbances from environmental features (Table 1). The other eleven controls have very low relative accuracies and therefore cannot be classified based on Table5. It is our belief that their accuracies have been degraded by the environmental features which surround them. Worthy of mention is G2 which used to be a national GNSS control station located in the middle of a football practice pitch for many years until recently (2012) when the university erected a two-storey building within 6 metres of the station (Fig.3). Table 6 shows that GNSS positioning now displaces it by 1.854m from its actual position, making it a “2metre – control” (with a relative accuracy of 1/114)! Such control stations may however, still achieve high accuracies with the Total Station instrument in spite of this deficiency with the GNSS.

This study therefore further confirms the fact that control points surrounded by environmental features such as tall buildings, tall fences, shade trees, etc are not suitable for the GNSS positioning technique rather, Total Station and other conventional survey methods (not affected by such features) should be preferred. The authors therefore recommend, from the study, that it is important to, once-in-a-while, re-evaluate existing GNSS controls to determine whether their accuracy has been degraded by features which have sprouted around them over time.

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