Error Propagation in the Nigerian Geodetic Network: Imperatives of GPS Observations to Strengthen Network

Lawrence Layi ARINOLA, Nigeria

Key Words: Geodetic Control Networks, Errors, GPS Observations

SUMMARY

Geodetic Control Networks and by extension Survey and Mapping which is the foundation of all physical, social and economic development has suffered neglect in the hands of successive Governments in the developing countries. In some of these countries, maps as old as forty years are still the most current in their archives, while the process of re-observation of the Geodetic Control Networks which were established about fifty years ago, is yet to commence.

For accurate and efficient policy decisions to be taken without bureaucratic bottlenecks, the development and utilization of Geographic Information System whose accuracy and effectiveness is dependent on an error free Geodetic Control Network cannot be overemphasized.

The development of Satellite technology, especially its application in navigation through the use of GPS has opened a new vista in the observation and strengthening of Geodetic Control Networks worldwide. Most developed countries have utilized the GPS to modernize their Control Networks. It is high time the developing countries are made aware of the error in their existing control networks and the need to modernize and re-observe these networks using modern technology. (the Global positioning System (GPS)).

Error Propagation in the Nigerian Geodetic Network: Imperatives of GPS Observations to Strengthen Network

Lawrence Layi ARINOLA, Nigeria.

1. INTRODUCTION

Technological advancement in the area of instrumentation and space (satellites in orbit) has impacted positively on the mode of observation of geodetic control networks. Most countries have had to completely re-observe or strengthen their control network using Global Positioning Systems. Onabajo O. in (6) highlights the efforts that have been made to carry out GPS observations to strengthen the Nigerian Geodetic Network. However, these efforts appear not to be far reaching enough hence the discovery of errors within the system which appears to increase away from Minna (triangulation point L40) the origin of Nigerian Survey.

The primary aim of this paper is to bring into focus the errors detected within the Nigerian Geodetic Network (using primary data (GPS) observations) at some locations in Nigeria.

The set objectives are:

- To determine the magnitude of error in the Nigerian control network
- To suggest procedural methodology through which strengthening or complete re-observation will be carried out.
- To make suggestions as to how to overcome the "no funds" syndrome which has stalled efforts at carrying out the strengthening cum re-observation.

2. HISTORY OF THE NIGERIAN GEODETIC NETWORK

The Nigerian Geodetic Control Network was observed by terrestrial measurements of angles and distances (bases). The observations took place between the late 1940's and early 1960's. A Triangulation Station at Minna (L40) was selected as the origin of the network. The projection used for the Datum is Clark 1880 (modified) (Onabajo O.; 2006. History of the Nigeria Geodetic Network))

The geodetic network was established in hierarchical manner as an array of triangles. Observations were carried out in series of chains and categorized as Primary Chain which consists of Primary triangulation points, Secondary Chain which consists of the secondary triangulation points and Tertiary Chain which consists of the tertiary triangulation points. Traverse points were used to augment the network in the southern and northern parts of the country where the topography was not conducive for the establishment of triangulation points due to non availability of hills and high grounds.

2.1 Primary/First Order Triangulation Chain

Each chain was identified by an alphabetical number which started from A and ended at U. Hence, there are a total of 21 chains. (Fig 1). A typical primary triangulation point is numbered thus B8 where B indicates that the point is located in the B chain and 8 is the pillar number.

2.2 Secondary/Second order Triangulation points.

These are a breakdown from the primary points. Secondary points within each chain have the chain alphabet preceded by X, hence a typical secondary triangulation point is numbered thus XJ800 where X indicates that it is a secondary triangulation point, J indicates that it lies within the J chain and 800 indicates the pillar number.

2.3 Tertiary/Third Order Triangulation Points

These are a further breakdown of the secondary triangulation points. Tertiary points within a chain has the chain alphabet preceded by Y, hence a typical tertiary point is numbered thus YK500 where Y indicates that the point is tertiary, K indicates that it falls in the K chain and 500 is the pillar number.

2.4 Location of the Control Stations

The existing control stations were located to satisfy the method of observation (triangulation). They were located on hills and high grounds to ensure intervisibility of lines of sight over appreciable distances. Rural settlements (which existed within a reasonable distance from these stations) have ceased to exist because of rural-urban migration and as a consequence of re-alignment and re-routing of roads and highways. Thus some of the stations that were located close to these settlements and highways are now many kilometers away from new settlements and current alignment of highways as they are now.

In view of the aforementioned, most of the stations have neither been visited nor utilized in any manner since their establishment.

With the availability of the (GPS) technology, it is imperative that stations can be sighted with greater flexibility with regard to user needs (i.e.) ease of accessibility and proximity to settlements.

3. EFFORTS AT STRENGTHING OF NETWORK

According to (Onabajo O.) in (6), the 12th parallel survey of the 1970's was integrated into the network. So also was Base and Scale check measurements (dates of these base and scale check measurements were not given). Some (16) of the primary triangulation points were integrated into the African Doppler Survey ADOS program of the early 1980's.

The first major effort at extension/densification/strengthening was made in the 1990's, when the Federal Survey Department (FSD) now Office of the Surveyor General of the Federation acquired five(5) number Dual Frequency GPS receiver Ashtech XII. These equipments were used to provide over 600 geodetic control stations to strengthen the network. The observation spanned between 1990 and 2002. However no major effort has been made towards the determination of the error in the network since the advent of GPS, which made its debut as a cumbersome piece of box as indicated in fig. 2 as compared to the current miniaturized size as indicated in fig. 3.

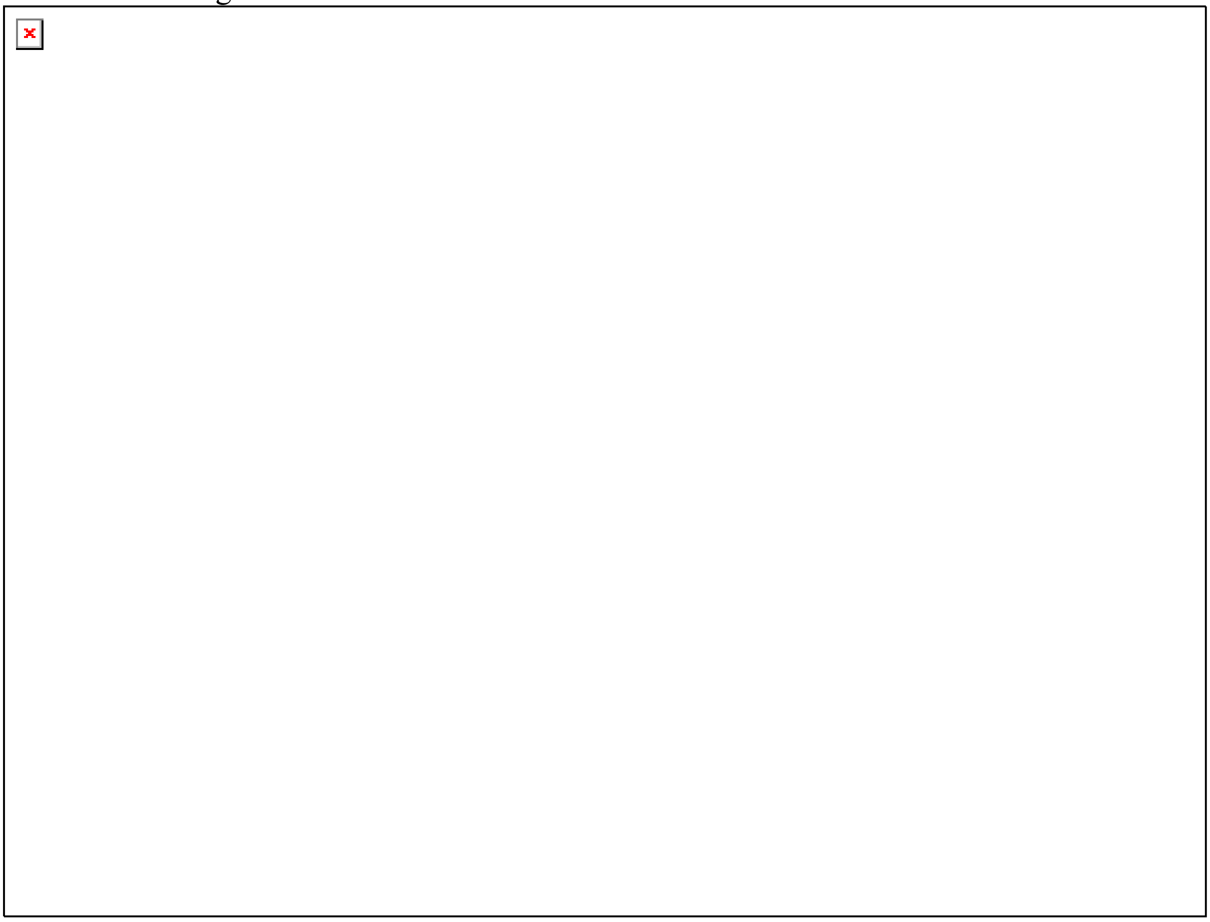

Fig. 1 Map of Nigeria showing the Geodetic Network in chains

The specification of the Wild Magnazox GPS receiver (fig 2) of 1985 was given in (4) as 10mm + 2ppm (horizontal) and the weight of the recieiver was 14.4kg compared with that of the integrated Radian IS (fig 3) with quoted accuracy in (7) of 3mm + 0.5mm ppm (horizontal) and 10.0mm +1ppm (vertical). The weight of the receiver was given as 1.6kg.

Fig. 2. Picture of Magnavox Mx1502B GPS Receiver as it was in 1988.

Fig. 3. Picture showing the Sokkia Radian IS Dual frequency Integrated GPS in 2006.

3. ERROR IN THE NIGERIAN GEODETIC NETWORK

During a routine cadastral survey exercise in Lagos in the year 2005, the author had cause to use a hand held GPS (Garmin 12XL) to locate an existing control point whose control had earlier been supplied by the relevant authority (the office of the Surveyor General of the Federation). The discrepancy of the supplied coordinates (in UTM) and those obtained using the hand GPS at estimated positional error (EPE3) was about 15m which contrasted sharply with the result normally obtained by the author around the Federal Capital City of Abuja where he practices. Out of curiosity, a single frequency (LI) post processing GPS (Promark II) was deployed to carry out further investigation. The result is shown in table 1:

	BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCE	
STATION	NORTH (m)	EAST(m)	NORTH(m)	EAST (m)	ΔN	ΔE
ORK 1	712080.565	549702.789	712070.767	549705.514	+9.798	-2.725

Table 1

This was the first indication that there exists an error in the network whose magnitude needs to be determined.

4.1 Determination of magnitude of Error in the Network

The following equipments were deployed to carry out GPS observations in static mode with a minimum observational time of four (4) hours, to cater for baseline errors and ensure that a sufficient number of satellites were logged unto. Stations selected were those where there was minimum obstruction to eliminate obstruction errors. The locations where the observations were carried out were Ibadan, Abuja, and Jere (along Abuja – Kaduna road).

The GPS equipments used to acquire the necessary primary data (GPS observations) are: -

- Single frequency post processing(LI) GPS Promark II by Thales Navigation.
- Single frequency post processing(LI) GPS Promark III by Thales Navigation.
- Dual frequency (LI, L2) GPS (Radian IS by Sokkia) with RTK capability.

The results of the observations are listed in tables 2, 3, 4 and 5.

AT IBADAN

STATION	BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCES	
	NORTH (m)	EAST (m)	NORTH (m)	EAST (m)	ΔN	ΔE
ICS1181P	822552.507	605081.023	822543.105	605083.474	+9.402	-2.451
ICS1616P	810228.848	596652.435	810219.899	596654.188	+8.949	-1.753
OFF1	819019.181	602477.769	819010.713	602480.201	+8.468	-2.432

Result of Single Frequency Post Processing GPS (Promark II) Operated in Static Mode
Table 2:

AT ABUJA

STATION	BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCES	
	NORTH (m)	EAST (m)	NORTH (m)	EAST (m)	ΔN	ΔE
FCT4159S	1003742.860	326124.422	1003742.403	326125.31	0.457	-0.888
FCT4154S	1003831.285	329953.882	1003830.826	329954.752	0.459	-0.87
OFFICE (ZN3)	1001924.051	332433.892	1001923.594	332434.789	0.457	-0.897
XJ1809	996246.858	353193.001	996246.455	353193.774	+0.403	-0.773
XJ786	993664.579	321094.480	993664.355	321095.545	+0.224	-1.065

Result of Dual Frequency RTK GPS (Sokkia Radian IS) Operated in Static Mode
Table 3:

AT ABUJA

STATION	BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCES	
	NORTH (m)	EAST (m)	NORTH (m)	EAST (m)	ΔN	ΔE
FCT4159S	1003742.860	326124.422	1003743.995	326126.300	-1.135	-1.878
FCT28P	996356.646	325511.894	996355.752	325512.344	0.894	-0.450
FCT26P	999001.714	328227.188	999000.793	328227.608	0.921	0.420
FCT224P	1025283.939	317590.174	1025284.835	317587.784	-0.896	2.390

Result of Single Frequency Post Processing GPS (Promark II) Operated in Static Mode
Table 4:

AT JERE

STATION	BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCES	
	NORTH (m)	EAST (m)	NORTH (m)	EAST (m)	ΔN	ΔE
XJ513	1058381.492	327788.253	1058382.057	327786.368	-0.565	1.885
XJ513	1058381.492	327788.253	1058382.306	327788.071	-0.814	0.182

Result of Single Frequency Post Processing GPS (Promark II) Operated in Static Mode
Table 5:

The results of the GPS observations in tables 1,2,3,4 and 5 can best be described as inconclusive. However, it is an indication of:

the probable magnitude of error in the network at these locations.
the fact that the magnitude of the error in the network increases away from the datum (L40 at Minna)

The reasons for the inconclusiveness of the above are:

- Internal consistency of the two types of GPS used for the observations have not been investigated.
- Not all sources of errors in GPS observations were adequately addressed. These errors include but not limited to obstructions, satellite geometry, occupation time, multipath effects, atmospheric conditions, baseline length etc.

However, the following were adequately catered for:

Number of satellites - Not less than six (6) satellites were logged on to during each of the observations.
Obstruction – Most of the sites chosen were devoid of obstructions.
Occupation time – was adequately catered for. At least four (4) hours, and at most seven (7) hours was spent when observations were carried out with the single frequency Promark II while four(4) hours was spent to log onto satellites using the dual frequency Sokkia Radian IS. Static method of observation was utilized in both cases.
Baseline Length – by virtue of the occupation time, the baseline length error was catered for
Other sources of error such as multi-path effects, atmospheric condition were not addressed at all.

4.2 Consistency of GPS Results

To determine the consistency of the two types of global positioning equipment used for the study, static observations were carried out at two locations at different days as listed in tables 6 and 7

EQUIPMENT: PROMARK II (SINGLE FREQUENCY) GPS
LOCATION: EWEKORO

Date	Station	Easting	Northing	Height	Length of Obs.	E-meanE	N-meanN	H-meanH
24/4/06	QB01	521227.304	764821.881	46.158	4hr 51min	-0.296	1.611	-0.648
23/4/06	QB01	521227.534	764820.540	45.453	7hr 21min	-0.066	0.270	-1.353
21/4/06	QB01	521228.064	764819.431	46.011	7hr 51min	0.464	-0.839	-0.795
16/4/06	QB01	521227.555	764820.411	46.307	7hr 30min	-0.045	0.141	-0.499
15/4/06	QB01	521227.770	764820.304	48.650	7hr 57min	0.170	0.034	1.844
14/4/06	QB01	521227.114	764820.291	48.116	7hr 39min	-0.486	0.021	1.310
13/4/06	QB01	521227.862	764819.031	46.950	7hr 15min	0.262	-1.239	0.144
MEAN VALUES:		521227.600	764820.270	46.806				

Result of Single Frequency Post Processing GPS (Promark II) Operated in Static Mode

Table 6:

EQUIPMENT: PROMARK II (SINGLE FREQUENCY) GPS
LOCATION: IBADAN

Date	Station	Easting	Northing	Height	Length of Obs.	E-meanE	N-meanN	H-meanH
25/1/06	OFF1	602482.446	819014.180	259.587	6hr 04min	0.735	0.660	1.059
23/1//06	OFF1	602481.906	819013.227	258.874	6hr 04min	0.195	-0.293	0.346
20/1//06	OFF1	602481.644	819012.644	256.805	6hr 25min	-0.067	-0.876	-1.723
18/01/06	OFF1	602482.045	819014.306	258.499	6hr 00min	0.334	0.786	-0.029
04/05/06	OFF1	602480.181	819012.458	258.879	7hr 07min	-1.530	-1.062	0.351
MEAN VALUES:		602481.711	819013.520	258.528				

Result of Single Frequency Post Processing GPS (Promark II) Operated in Static Mode

Table 7:

The spread as indicated in the result in tables 6 and 7 above is a measure of relative consistency of the GPS observational result when used to determine the position of a point independently.

The spread can be accounted for by satellite Geometry/configuration which does not remain the same for observational epochs.

Table 8 indicates a high level of consistency in GPS results when an initial point is held fixed and vectors are used to compute the position of subsequent stations that need to be fixed.

STATION		BOOK VALUE		DIRECT SATELLITE FIX		DIFFERENCES	
FROM	TO	DISTANCE (m)	BEARING (m)	DISTANCE (m)	BEARING (m)	ΔD (m)	ΔB
FCT4159S	HOME	3696.415	13° 07' 30"	3696.435	13° 07' 26.4"	-0.020	3.6"
FCT4159S	41545	3830.481	88° 40' 37.2"	3830.463	88° 40' 37.2"	0.018	0.0"
FCT4159S	ZN3	6566.390	106° 04'51.6"	6566.399	106° 04' 48"	-0.009	3.6"
HOME	FCT4154S	4612.032	139° 35' 02.4"	4612.057	139° 35' 06"	-0.025	3.6"
HOME	ZN3	7699.612	134° 43' 44.4"	7699.653	134° 43' 44.4"	-0.041	0.0"

Comparison of Bearings and Distances of Book Values and Direct Satellite Fix Values

Table 8

5. EXPERIENCE OF OTHER COUNTRIES:

The discovery of an error of the magnitude of 9m appears shocking but this situation is not peculiar to Nigeria. G. Block and G.Rowe in (1) confirmed that the Geodetic Datum of New Zealand (NZGD49) was discovered to have an error (described by them as distortion) of 5m. Jan KOSTELECKY and Jan PYTEL in (5) claimed that the Czeck Republic carried out the process of GPS densification of its control Network between year 1995 and 2003. The reason for this GPS densification was not stated by the authors but may not be unconnected with the discovery of an error in the old Network, which was observed by classical method of Triangulation, Traverse, Tri-lateration and Spirit leveling.

The Geodetic Survey Points determined by these classical methods was described by David R. Doyle in (3) as "not directly 'GPS able'."

6. RECOMMENDATIONS:

The office of the Surveyor-General of the Federation in carrying out its statutory function in ensuring that Nigeria has an error free, internally consistent and externally compatible Geodetic Control Network should commence the process of strengthening/re-observation of the network by implementing some or all of the following;

Set up a committee made up of Geodesists from the Academia and Surveyors from the Public and private sectors of the economy to draw up a road map of the way forward in correcting any inherent errors in the existing Geodetic control network.

The terms of reference of the committee should include but not limited to the following:-

(a) Wide consultation with stake holders.
(b) Enumeration to determine the number of dual frequency GPS receivers available in the country.
(c) Draw up specifications for observation of Geodetic Control Network using GPS.

Purchase Dual Frequency GPS receivers like it did in the1990s for the strengthening/re-observation of the network.

Encourage other stakeholders such as the States Survey Departments, Higher Institutions (that have departments of survey and Geo-informatics), and Private Survey and Geo-informatics Companies, (who have the requisite equipment) to actively participate in the re-observation of the network in what is here-in described as Public, Private and Institutional Participation (PPIP). The terms and conditions of such participation should be mutually discussed and agreed upon bearing in mind that it is a national assignment.

Delay the implementation of the National Spatial Data Infrastructure (NSDI), until the inconsistencies in the geodetic network has been resolved.

Seek international cooperation and aid of friendly Nations in expediting the re observation program.

Establish a national network of GPS Continuously Operating Reference Stations (CORS) which according to David R. Doyle in (3) "will make pseudo-range and carrier-phase measurements accessible to the public for use in a wide range of geodetic, cadastral, and engineering surveying applications, mapping and charting navigation." Availability of CORS will reduce the requirements for additional GPS receivers for differential positioning problems.

7. CONCLUSION.

The Nigerian geodetic control network has served the Mapping and Cadastral needs of Nigeria well over the past sixty years, but with a distortion of about ten meters, it cannot meet the requirements of new technologies such as GPS. It is also capable of creating an irreconcilable problem during the implementation of a country wide GIS where data from different sources have to be integrated.

Having established that satellite based Global Positioning System (GPS), can now provide homogeneous country wide geodetic network, a new homogeneous geodetic control network whose control points will be easily accessible to prospective users all over Nigeria is desirable and should be implemented without further delay.

REFERENCES

1. Blick G. & Rowe G (undated) Progress towards a New Geodetic Datum

for New Zealand (unpublished).

2. Cecep Subarya (undated) The present status of Indonesian Tide Gauge Network and Indonesian permanent GPS Station Network (unpublished)

3. David R. Doyle (undated) Development of the National Spatial Reference System. (Unpublished).

4. Global Surveys Limited (1985) Land and Mineral Surveying (An official journal of the Royal Institution of Chartered Surveyors

5. Kostelecky Jan & Pytel Jan (2004) Modern Geodetic control in the Czeck Republic, Based on the Densification of EUREF Network.) (Unpublished).

6. Onabajo O. (2006) History of Nigeria Network Summarized (Unpublished)

7. Sokkia Pte. (2003) Radian IS GPS (Specifications)

CONTACT

L. Layi Arinola
Arinmap Consultants Limited
Plot 1427 Abidjan Street
Wuse Zone 3
Abuja
NIGERIA
Email: layiarinola@yahoo.com