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Assessment of Positioning with IGS-Real Time Service Data at Enugu, Nigeria

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Abstract

The non-availability of GNSS control points around local regions where access to Continuously Operating Reference Stations (CORS) is difficult or non-available in developing countries, such as Nigeria, has become a major challenge to accurate positioning by differential GNSS method. Also, acquisition of two units of dual frequency GNSS receivers is becoming too costly and unaffordable for users due to economic downturn. With the advent of International GNSS Service (IGS) - real-time service (IGS-RTS) which provides corrections that can be applied in real time, precise point positioning (PPP) with just a receiver unit is now a possibility. This study evaluates this new positioning technique (IGS-RTS) at Enugu, Nigeria, by comparing its results with those obtained from accurate post-processed differential GNSS static observations. The study shows 2-dimensional horizontal root mean square (RMS) discrepancy between both methods at 39% confidence limit is 0.039m and 0.095m at 95% confidence limit. The discrepancy for height was 0.121m at 95% confidence limit. The IGS-RTS corrections were available 100% during the 4 hours 16 minutes duration of observations on six ground control points. Thus, the IGS-RTS data will be very useful in some aspects of cadastral surveys, engineering surveying and GIS (Geographic Information System) in Enugu locality.

Keywords: IGS-RTS Data, GNSS Static Positioning, Validation

1. Introduction

Since the GPS technology became available to the public in the 1980s, various positioning techniques have been developed. These include the “autonomous” (or stand-alone) and the “relative positioning” (or differential GPS (DGPS) or “Interferometric”) methods.

The autonomous method applies civilian code signals in a hand-held GPS receiver to determine low grade geocentric positions at about 3 metre accuracy level or a dual-frequency GPS receiver in precise point positioning to achieve decimeter accuracy. On the other hand, the DGPS method applies two or more receiver units which observe the same set of satellites simultaneously from two or more stations in an interferometric mode. The Master unit is setup on a station with known coordinates while the other unit (called “rover”) is setup over a station whose position is yet to be determined. In the field work, the master unit either sends corrections to the rover unit (i.e. “ordinary DGPS”) or sends its observed data to the rover unit for “differencing” in real-time or post-processed kinematic/static positioning. The latter is called “precise DGPS”. The DGPS methods yield accuracies that could be as high as a few millimetres (mm) and consequently are very useful in Surveying and Geodetic applications. Details of autonomous and DGPS methods are given in (Ghilani and Wolf, 2012 [6]; Seeber, G, 2003 [13]; Leick A, 2004 [12]; and, Hofmann-Wellenhof, Lichtenegger, and Collins, 1992).

The major challenge however, in the use of the DGPS technique in some developing countries such as Nigeria, is the non-availability of GPS control points, in sufficient geographic spread and density, for use as “Master” station. Also, scarcity of Continuously Operating Reference Stations (CORS) is a worrisome challenge because they are sometimes more than 500km away from remote areas and may not stream data for weeks.

Happily, the precise point positioning (PPP) technique has been developed in recent times and requires only one dual frequency receiver unit (instead of a pair). The PPP technique is well described in (Kouba and Heroux, 2001) [11]. Also, in 2010, the International GNSS Service (IGS) launched its real-time service (IGS-RTS) for GNSS orbit and clock correction service that enables real-time precise point positioning worldwide. The data are also expected to be suitable for time synchronization and disaster monitoring in all parts of the world (www.rts.igs.org). These attributes make IGS-RTS potentially very important to developing countries.

The PPP-based positioning solution using real-time IGS-RTS service is however, still under investigation by many researchers to examine and analyze its accuracy and solution performance in static and kinematic modes (Elsobeiey and Al-Harbi, 2015; and El-Diasty and Elsobeiey, 2015) [5, 3]. Even though the IGS says that RTS provides orbit and clock parameters at an accuracy of 5cm and 0.5nanoseconds (ns) (~15cm) respectively (see Table 1.1), studies have shown it is not always so. For example, (Hadas and Bosy, 2015) [7] shows that GPS orbit and clock outliers can be as high as 30cm and 20cm respectively in different parts of the world, the corresponding GLONASS orbit and clock outliers can be as high as 50cm and 75cm respectively. (El-Diasty and Elsobeiey, 2015) [3] in their study of the suitability of IGS-RTS for maritime application achieved mean and maximum errors of 0.07m and 0.22m respectively. They achieved also, 2-dimensional horizontal accuracy (RMS) of 0.08m at 39% confidence limit and 0.19m at 95% limit. Hence, there is need for the Surveyor to verify the actual achievable positioning accuracy within his/her locality in order to determine to what extent he/she can rely on RTS data. This study has therefore set for itself, the goal of verifying the level of accuracy achievable by RTS in Enugu, Nigeria. We have however, restricted our study to position determination alone.

In our study, we determined the positions of six ground control points (GCPs) within the compound of the University of Nigeria, Nsukka (Enugu-Campus, UNEC), by both IGS-RTS and differential static GPS methods and results compared.

Table 1.1: Precise GPS satellite orbits and clock corrections as provided by the IGS (Hadas and Bosy, 2015) [7]

Product	Parameter	Accuracy	Latency
Real-time service (IGS-RTS) (estimated)	Orbit	5cm	25s
	Clock	0.5ns	
Ultra rapid (predicted)	Orbit	10cm	Real-time
	Clock	5ns	
Ultra rapid (estimated)	Orbit	3cm	3hrs
	Clock	0.2ns	
Rapid (estimated)	Orbit	2.5cm	7hrs
	Clock	0.10ns	
Final (estimated)	Orbit	2cm	14days
	Clock	< 0.10ns	

1.1 Study Area

The research work was carried out within the University of Nigeria, Nsukka (Enugu-Campus) (UNEC), Enugu State, Nigeria. Enugu town is the capital city of Enugu State which is geographically located at the south eastern part of Nigeria (Fig 1.1). It falls between latitudes 6° 25' 30"N and 6° 25' 40"N; and longitudes 7° 29' 50"E and 7° 30' 25"E respectively. Enugu state has a landmass of approximately 7,315 km^2.

Fig 1.1: Study area in Enugu, Nigeria

2. IGS-Real Time Service

The International GNSS Service (IGS) real-time service (IGS-RTS) is operated as a public service in which users are offered free access to products through subscription. Its services are located at (www.rts.igs.org) and are based on the IGS global infrastructure of network stations, data centres and analysis centres that provide world standard high-precision GNSS data products. 160 station operators, multiple data centres, and 10 analysis centres around the world participate in the Service.

RTS is currently offered as a GPS-only operational service. IGS partners with Natural Resources, Canada (NRCan), the German Federal Agency for Cartography and Geodesy (BKG), and the European Space Agency's Space Operations Centre in Darmstadt, Germany (ESA/ESOC). It uses the format of the RTCM standard for State Space Representation (RTCM-SSR) to stream RTS corrections via the NTRIP protocol. SSR corrections include satellite ephemeris, clock, and ionospheric corrections. Some of the product streams (IGS01, IGC01, IGS02, and IGS03) and their corresponding message numbers are shown in Table 2.1. Users can choose to download any data stream of their choice (either "IGS combined data" or "Analysis Centre (AC) data"). Positions are given in the International Terrestrial Reference Frame 2008 (ITRF08). More details are given at the IGS-RTS home page (www.rts.igs.org); Kim and Kim 2015 [10]; Hadas and Bosy 2015 [7]; etc.

Table 2.1: Precise GPS satellite orbits and clock corrections provided by the IGS

Stream Name	Description	Ref. Point	RTCM Messages	Provider/ Solution ID	Bandwidth (kbits)	Software
IGS01	Orbit/Clock Correction, Single-Epoch Combination	APC	1059(5),1060(5)	258/1	1.8/sec	ESA/ESOC
IGC01	Orbit/Clock Correction, Single-Epoch Combination	CoM	1059(5),1060(5)	258/9	1.8/sec	ESA/ESOC
IGS02	Orbit/Clock Correction, Kalman Filter Combination	APC	1057(60), 1058(10), 1059(10)	258/2	0.6/sec	BKG
IGS03	Orbit/Clock Correction, Kalman Filter Combination	APC	1057(60), 1058(10), 1059(10), 1063(60)	258/3	0.8/sec	BKG

2.1 Mathematical Framework of IGS_RTS Corrections

Orbit corrections ($\delta\vec{X}$) and clock corrections (δC (t)) are updated and applied to the broadcast position of the satellite in its orbit ($\vec{X}_{broadcast}$) and broadcast clock ($t^{sat}_{broadcast}$) respectively, to obtain precise satellite position ($\vec{X}_{precise}$) and precise clock ($t^{sat}_{precise}$).

To obtain the precise satellite position in its orbit ($\vec{X}_{precise}$), we apply $\delta\vec{X}$ to $\vec{X}_{broadcast}$ as in (Kim and Kim, 2015 [10]; and, Hadas and Bosy, 2015) [7]:

$$\vec{X}_{Pr\,ecise} = \vec{X}_{broadcast} - \delta\vec{X} \qquad (2.1)$$

The $\vec{X}_{broadcast}$ is usually given in an earth-centered, earth-fixed (ECEF) coordinate system.

However, $\delta\vec{X}$ is derived from raw RTS correction ($\delta\vec{O}(t)$) which is not expressed in ECEF but rather, in radial, along-track, and cross-track (RAC) coordinate system. Since in eqn (2.1), $\vec{X}_{broadcast}$ is expressed in an ECEF system, there is need to also express $\delta\vec{X}$ in the ECEF system. The raw corrections ($\delta\vec{O}(t)$) are therefore transformed from RAC to ECEF system with eqn (2.2) to obtain $\delta\vec{X}$:

$$\delta\vec{X}(t)_{ECEF} = [\vec{e}_r \vec{e}_a \vec{e}_c]\delta\vec{O}(t)_{RAC} \qquad (2.2)$$

Where,

$\vec{e}_r$, $\vec{e}_a$, and $\vec{e}_c$ are the unit vectors for radial, along-track, and cross-track coordinates, respectively.

$$\vec{e}_a = \frac{\vec{r}}{|\vec{r}|}, \vec{e}_c \frac{\vec{r}\times\dot{\vec{r}}}{|\vec{r}\times\dot{\vec{r}}|}, \text{ and } \vec{e}_r = \vec{e}_a \times \vec{e}_c$$

Where, $\vec{r}$ represents the satellite broadcast position vector and $\dot{\vec{r}}$, the satellite velocity vector.

(Hadas and Bosy, 2015) [7] shows that $\delta\vec{O}(t)$ corrections in eqn (2.2) are first updated from message reference time t_0 to current epoch t as in eqn (2.3) before being applied in eqn (2.2):

$$\delta\vec{O}(t) = \begin{bmatrix}\delta O_r \\ \delta O_a \\ \delta O_c\end{bmatrix}_{t_0} + \begin{bmatrix}\delta \dot{O}_r \\ \delta \dot{O}_a \\ \delta \dot{O}_c\end{bmatrix}(t - t_0) \qquad (2.3a)$$

Or,

$$\delta\vec{O}(t) = \delta\vec{O}(t_0) + \delta\dot{\vec{O}}(t - t_0) \qquad (2.3b)$$

Where, $\delta\vec{O}$ and $\delta\dot{\vec{O}}$ are the correction term and its velocity respectively.

On the other hand, the RTS clock correction, δC (t), is given as a correction to the broadcast clock offset. Similar to the orbit correction, the clock correction consists of the transmitted correction and its rate of change:

$$\delta C\,(t) = C_0 + C_1\,(t - t_0) + C_2\,(t - t_0)^2 \qquad (2.4)$$

where C_0, C_1, and C_2 represent the transmitted clock corrections. δC *(t)* is expressed as a correction-equivalent range unit, and the clock offset, δt (t) can be obtained by dividing δC *(t)* by the speed of light c:

$$\delta t\,(t) = \frac{\delta C\,(t)}{c} \qquad (2.5)$$

$$t^{sat}_{precise} = t^{Sat}_{broadcast} - \delta t(t) \qquad (2.6)$$

Types of IGS orbit and clock products available to users are shown in Table 1.1. More details can be obtained from (Kim and Kim, 2015) [10]; (El-Diasty and Elsobeiey, 2015) [3] and (Hadas and Bosy, 2015) [7].

2.2 IGS-RTS and Precise Point Positioning (PPP)

With a dual frequency GPS receiver whose firmware has a built-in precise point positioning (PPP) capability, RTS can be used anywhere in the world for highly accurate PPP provided internet access is available. A laptop personal computer (PC) should have either the BNC (BKG NTRIP Client) or the RTKLIB (Real-time Kinematic Library) open-source application installed in it and connected to the GPS receiver through its serial port (Fig 2.1). Once there is a live connection to the internet, the GPS receiver and software start taking decimeter level of observations or better accuracy from the IGS-RTS after an initial convergence time of 15 – 30 minutes. (El-Diasty and Elsobeiey, 2015) [3] achieved convergence after 20minutes of observation.

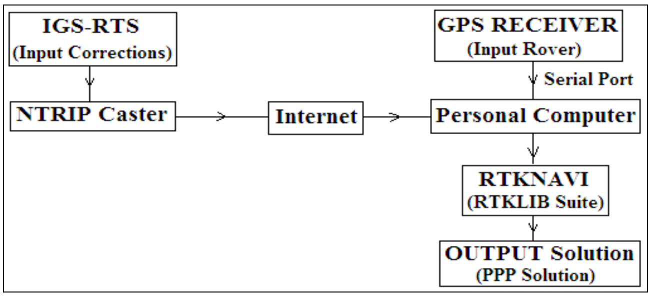

Fig 2.1: Flow diagram of GPS receiver PPP with IGS-RTS data

3. Methodology

A work flow-diagram for the research methodology is shown in Fig 3.1.

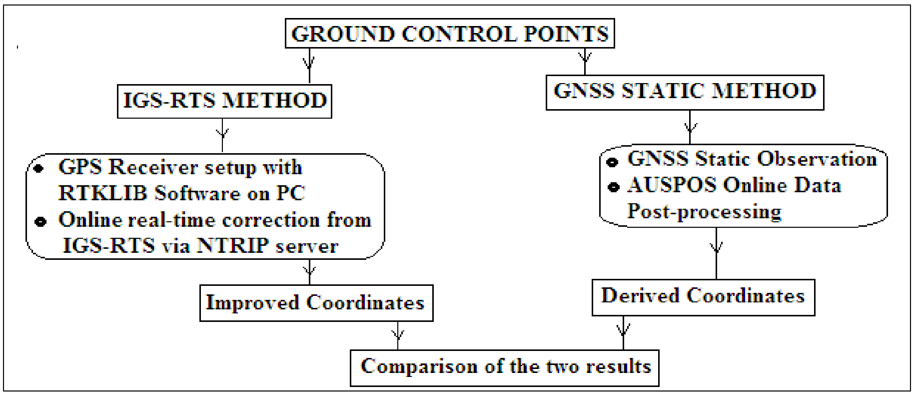

Fig 3.1: A flowchart of the design of the study

In the comparison, positions determined with the GNSS static method were adopted as reference/standard. (El-Diasty and Elsobeiey, 2015) [3] in their study used values obtained from real-time Kinematic (RTK) GPS as reference/standard.

3.1 GNSS Static Method

A unit of Leica 1203+ GNSS dual frequency receiver was used for the static observation at each ground control point (GCP) (the technical specifications of the instrument are given in Table 3.1). Having confirmed that the receiver was fit, the observations were carried out for at least two hours on each GCP between 10th and 13th August, 2017 (DOY 222 to 225). The receiver was configured to acquire data at 15 seconds interval (capture rate) at a mask angle of 15° at each setup. The observed data was converted to RINEX (Receiver Independent Exchange) format and sent for online processing on 02/11/2017 (DOY 306) by the AUSPOS online GPS processing service (version: AUSPOS 2.2), Australia which uses International GNSS Service (IGS) products (final, rapid, ultra-rapid depending on availability) to compute precise coordinates in ITRF. AUSPOS uses the Bernese (scientific) GNSS Software Version 5.2 for GNSS data processing (for more information on AUSPOS, visit its homepage at (http://www.ga.gov.au/geodesy/sgc/wwwgps/). All the data were optimally processed and positions given in the International Terrestrial Reference Frame 2014 (ITRF14). (El-Mowafy, 2011) [11] states that the use of the AUSPOS and CSRS-PPP (Canada) online engines for processing of static data from one unit of dual-frequency receiver gave precision at millimeter to centimeter for AUSPOS and decimeter precision for CSRS-PPP.

3.2 IGS-RTS Method

The dual frequency Hi-Target V90+ GPS receiver was used for the IGS-RTS PPP method because it had all the required accessories for the technique. (The technical specifications of the instrument are given in Table 3.1).

The RTKLIB/RTKNAVI software was properly installed in a laptop personal computer (PC) and the Hi-TargetV90+ dual frequency GPS receiver was connected to the PC via the serial port (Bluetooth could also be used), and the RTKNAVI real-time navigation program was launched.

The instrument was configured for reception of corrections from IGS servers as shown in Fig 3.2.

Table 3.1: Technical Specifications of GPS Receivers

Item	Leica GPS 1203 Receiver	HI-Target V90+ GPS Receiver
Type	Dual frequency	Dual frequency
Channels	72 Channels (GPS, 2 SBAS)	220 Channels (GPS, GLONASS, SBAS, GALILEO, BDS, QZSS)
Ports	1power, 3 serial, 1 controller, 1 antenna, 1 power/controller	1 mini USB, 1 5-pin serial for NMEA output, external devices, power, etc
Bluetooth	Bluetooth port	Dual mode BT4.0
Kinematic Accuracies	Horizontal: 10mm + 1ppm Vertical: 20mm + 1ppm	Horizontal: 10mm + 1ppm RMS Vertical: 2.5mm + 1ppm RMS **RTK:** Hor.: 8mm+1ppm; Vert.: 15mm+1ppm
Static Accuracies	Horizontal: 5mm + 0.5ppm Vertical: 10mm + 0.5ppm	Horizontal: 2.5mm + 1ppm RMS Vertical: 5mm + 1ppm RMS
Transmission/ Reception Formats	Leica proprietary, CMR, CMR+ RTCM: V2.1, 2.2, 2.3, 3.0, 3.1	CMR, CMR+, sCMRx RTCM: 2.1, 2.3, 3.0, 3.1, 3.2
DGPS	WAAS, EGNOS, NMEA 0183V3.00	NMEA 0183GSV, AVR, RMC, HDT,VGK, VHD, ROT, GGK, GGA, GSA, ZDA, VTG, GST, PJT, PJK, etc
Communication (Data Links)	Radio modem, GSM, GPRS, CDMA	Radio modem, Internal 3G, compatible with GPRS, GSM, and Network RTK

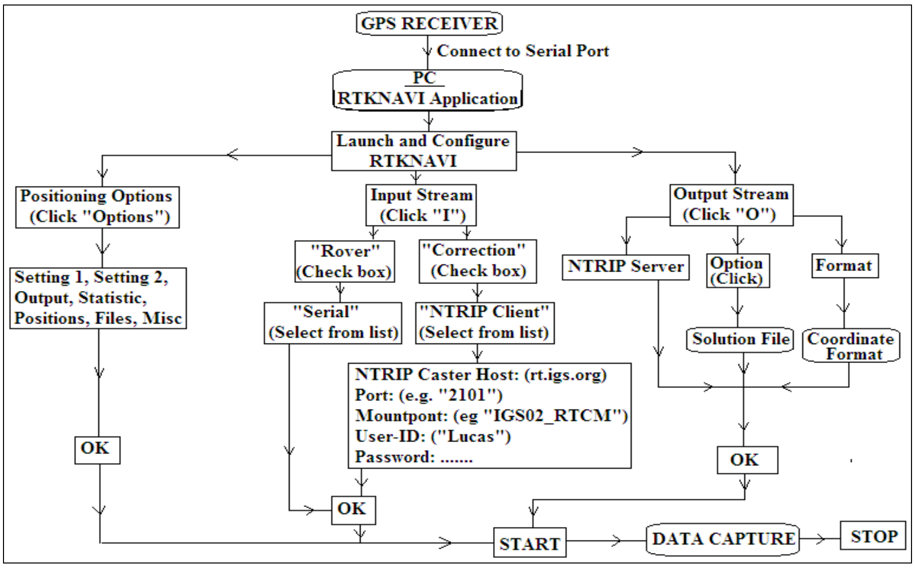

Fig 3.2: Configuration of RTKNAVI

4. Results and Discussions

4.1 Results for Differential GNSS Static Positioning

The results of the differential GNSS static positioning done with Leica 1203+ GNSS dual frequency receiver and processed online by AUSPOS with Bernese software v5.2 are shown in Table 4.1. The Cartesian (X, Y, Z) and geodetic (latitude ϕ, longitude λ and ellipsoidal height h) positions of the six ground control points (EN, D, NI05, CE, F, BN) were given in ITRF 2014 datum.

The percentage (%) ambiguity resolution (A.M.) of the solution indicates the success rate of the processing. Fifty percent (50%) or better for a baseline indicates a reliable solution (AUSPOS Report, 2017). For all the GCPs, the success rates were greater than 55% except for station BN (36.4%). Hence, the coordinates of BN obtained from static method are float solution and not reliable (see Table 4.1).

Geodetic positional uncertainties of the GCPs were determined at 95% confidence limit (according to the processing report from AUSPOS). The mean uncertainties for horizontal and vertical positions are ±0.021m and ±0.048m respectively; while the maximum are ±0.037m and ±0.059m respectively (see also Fig 4.1).

Table 4.1: ITRF2014 Coordinates from GNSS Static method processed by AUSPOS online Service

Station	ITRF 2014 Coordinates						Ambiguity Resolution (%)
	Cartesian (m)			Geodetic (±2σ)			
	X (m)	Y (m)	Z (m)	ϕ (DMS±m)	λ (DMS±m)	h (m)	
EN	6284329.245	827259.115	709227.124	6 25 37.211 ± 0.012	7 29 57.144 ± 0.030	228.361 ±0.059	63.7
D	6284344.244	827348.778	708978.913	6 25 29.085 ± 0.012	7 29 59.973 ± 0.017	226.989± 0.042	83.3
NI05	6284212.542	828008.422	709361.978	6 25 41.638± 0.010	7 30 21.815± 0.017	225.705±0.046	81.5
CE	6284306.317	827557.635	709171.545	6 25 35.354± 0.015	7 30 06.872± 0.037	238.274±0.046	55.6
F	6284324.431	827369.155	709138.789	6 25 34.319± 0.009	7 30 00.715± 0.020	228.003±0.040	70.0
BN	6284316.292	827359.503	709320.719	6 25 40.238± 0.011	7 30 00.438± 0.011	239.098±0.056	36.4

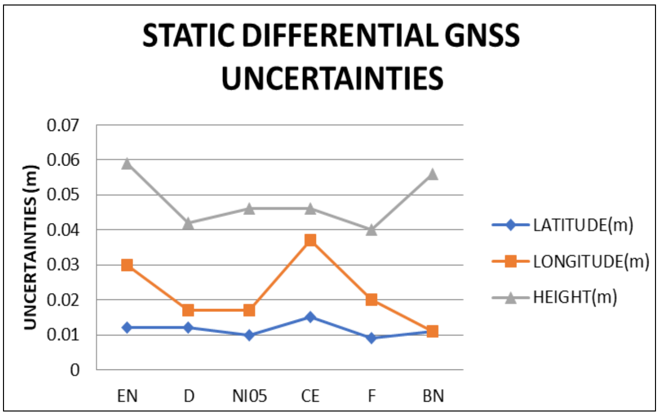

Fig 4.1: Uncertainties in differential GNSS static positioning

4.2 Results for IGS-RTS Positioning

The NTRIP caster host for our RTS positioning was (rt.igs.org) while the RTS corrections were streamed through NTRIP caster 2.0.21/2.0. The mount point was (IGS02_RTCM) at (latitude 50° N, longitude 10° E) with APC as its reference point. The RTCM stream message formats used were 1057(60), 1059(5), and 1060(5). The positions of the ground control points were given in the ITRF2008 datum (Table 4.2).

The mean uncertainties for latitude, longitude and height are ±0.024m, ±0.023m and ±0.027m respectively; while the maximum values are ±0.064m, ±0.066m and ±0.061m respectively (Table 4.2 and Fig 4.2). The ambiguity resolution at the GCPs ranged from 61% to 93% which indicate reliable (fixed) solutions (Table 4.3). The length of observation at each station is also shown in Table 4.3.

Table 4.2: ITRF2008 Coordinates (and precisions) obtained from IGS-RTS

Station	ITRF 2008 COORDINATES							
	CARTESIAN (±2σ) (m)			GEODETIC (±2σ)			UTM (Zone 32N)	
	X (m)	Y (m)	Z (m)	ϕ	λ	h (m)	N (m)	E (m)
EN	6284329.229 (±0.016)	827259.065 (±0.030)	709227.147 (±0.005)	6 25 37.212 (±0.003m)	7 29 57.142 (±0.028m)	228.342 (±0.018m)	710650.188	334023.190
D	6284344.212 (±0.015)	827348.793 (±0.007)	708978.921 (±0.013)	6 25 29.086 (±0.014)	7 29 59.974 (±0.006)	226.961 (±0.013)	710400.318	334109.455
NI05	6284212.524 (±0.002)	828008.421 (±0.004)	709361.996 (±0.009)	6 25 41.639 (±0.010)	7 30 21.815 (±0.003)	225.689 (±0..002)	710783.956	334781.691
CE	6284306.186 (±0.014)	827557.658 (±0.015)	709171.560 (±0.024)	6 25 35.355 (±0.022)	7 30 6.874 (±0.014)	238.149 (±0.018)	710592.274	334322.039
F	6284324.411 (±0.062)	827369.114 (±0.016)	709138.790 (±0.027)	6 25 34.319 (±0.030)	7 30 0.713 (±0.019)	227.978 (±0.061)	710561.000	334132.655
BN	6284316.264 (±0.036)	827359.219 (±0.071)	709320.707 (±0.069)	6 25 40.238 (±0. 064)	7 30 0.429 (±0.066)	239.032 (±0.052)	710742.830	334124.442

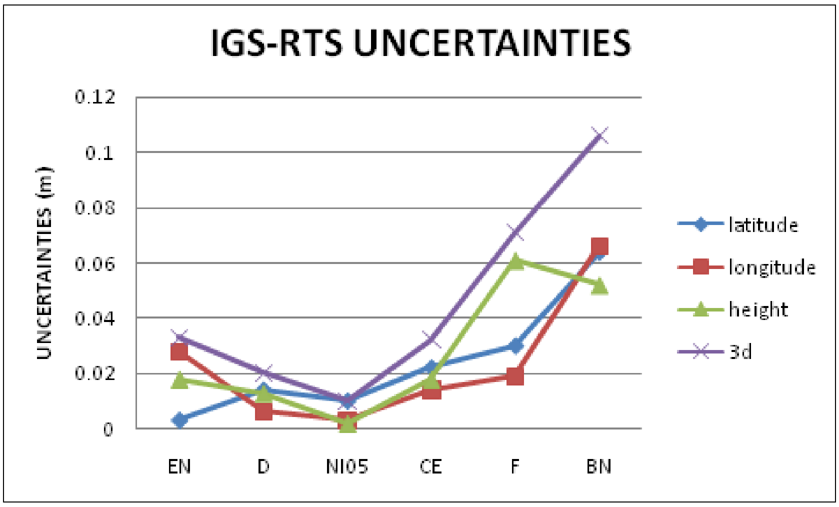

Fig 4.2: Uncertainties in IGS-RTS positioning

Table 4.3: Length of observation and Ambiguity Resolution

Date of Obs.: 11/11/2017 (DOY = 315); **Antenna Name:** High Target HITV90PLUS **Antenna Height:** 1.802m;			**Software:** RTKNAVI ver 2.4.2; **User ID:** LUCAS; **Obs. Used:** 5487/5526:99%	
S. No	Station	Fixed Ambiguity (%)	Time of Observation (Start/Stop)	Time Interval
1	EN	93	10:56:00/11:19:00	23minutes
2	D	72	11:46:00/12:03:00	17min
3	NI05	68	12:29:00/12:46:00	17min
4	CE	61	13:06:00/13:32:00	26min
5	F	76	13:52:00/14:22:00	30min
6	BN	78	14:41:00/15:12:00	31min

4.3 Comparison of IGS-RTS and GNSS Static Results

Tables 4.1 and 4.2 show that positions derived from GNSS Static and IGS-RTS were given in ITRF 2014 and ITRF2008 respectively. For accurate comparison of the two results, there is need to transform them to the same coordinate system. The ITRF2008 datum was chosen for the comparison because most of Nigeria's geodetic control data infrastructures are in that datum. Hence the ITRF2014 coordinates were transformed to ITRF2008. The transformation model (4.1) given by (Altamimi *et al*, 2016) [1] was used to transform from ITRF2014 to ITRF2008:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF2008} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF2014} + T + D\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF2014} + R\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF2014} \quad (4.1)$$

Where,

D = the scale factor

$$T = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} = \text{the translation vector}$$

$$R = \begin{bmatrix} 0 - R_z R_y \\ R_z 0 - R_x \\ -R_y R_x 0 \end{bmatrix} = \text{the rotation matrix.}$$

The values of the transformation parameters T_x, T_y, T_z, D, R_x, R_y and R_z are given in Table 4.4 (Altamimi *et al*, 2016) [1].

Table 4.4: Transformation Parameters at Epoch 2010.0 from ITRF2014 to ITRF2008 (Altamimi *et al*, 2016) [1]

T_x (mm)	T_y (mm)	T_z (mm)	D (ppb)	R_x (mas)	R_y (mas)	R_z (mas)
1.6±0.2	1.9±0.1	2.4±0.1	-0.02±0.02	0.00±0.06	0.00±0.06	0.00±0.06

The transformed ITRF2008 coordinates obtained by the GNSS static method are given in Table 4.5.

Table 4.5: ITRF2008 coordinates transformed from ITRF2014 GNSS Static Solutions

Station	ITRF 2008 COORDINATES							
	CARTESIAN (m)			GEODETIC (±2σ)			UTM (Zone32N)	
	X (m)	Y (m)	Z (m)	ϕ (DMS±m)	λ (DMS±m)	h (m)	N (m)	E (m)
EN	6284329.2465	827259.1169	709227.1264	6 25 37.211 ± 0.012m	7 29 57.144 ± 0.030m	228.363 ±0.059m	710650.161	334023.238
D	6284344.2455	827348.7799	708978.9154	6 25 29.085 ± 0.012m	7 29 59.973 ± (0.017m)	226.98991 ± 0.042m	710400.310	334109.436
NI05	6284212.5435	828008.4239	709361.9804	6 25 41.639 ±0.10	7 30 21.815 ±0.017	225.707 ±0.046	710783.939	334781.692
CE	6284306.3185	827557.6369	709171.5474	6 25 35.354 ±0.015	7 30 06.873 ±0.037	238.276 ±0.046	710592.247	334322.002
F	6284324.4325	827369.1569	709138.7914	6 25 34.319 ±0.009	7 30 00.715 ±0.020	228.005 ±0.040	710560.997	334132.695
BN	6284316.2935	827359.5049	709320.7214	6 25 40.238 ±0.011	7 30 00.438 ±0.011	239.100 ±0.056	710742.836	334124.722

The differences between the positions of the GCPs obtained from the two methods are also shown in Table 4.4 and Fig 4.3.

Table 4.6: Differences between positions obtained from IGS-RTS and GNSS Static method

Station	Cartesian Coordinates				Geodetic Coordinates			UTM Coordinates		
	ΔX (m)	ΔY (m)	ΔZ (m)	3D	Δϕ (")	Δλ (")	Δh (m)	ΔN (m)	ΔE (m)	2D
EN	0.018	0.052	-0.021	0.059	0.001	-0.002	-0.021	0.027	-0.048	0.055
D	0.034	-0.013	-0.006	0.037	0.001	0.001	-0.029	0.008	0.019	0.021
NI05	0.02	0.003	-0.016	0.026	0.0	0.0	-0.018	0.017	-0.001	0.017
CE	0.133	-0.021	-0.013	0.135	0.001	0.001	-0.111	0.027	0.037	0.046
F	0.022	-0.043	-0.001	0.048	0.0	-0.002	-0.027	0.003	-0.04	0.040
BN	0.03	-0.286	-0.014	0.288	0.0	-0.009	-0.068	-0.006	-0.28	0.280
$RMS^{3D}_{39\%}$ = 0.135m		$RMS^{3D}_{95\%}$ = 0.329m			$RMS^{\Delta h}_{95\%}$ = 0.138m		$RMS^{2D}_{39\%}$ = 0.12m		$RMS^{2D}_{95\%}$ = 0.292m	

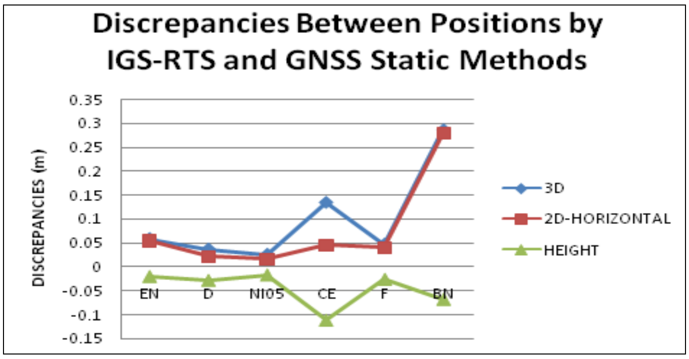

Fig 4.3: Discrepancies between positions from IGS-RTS and GNSS Static methods

From Table 4.6 and Fig 4.3, it can be seen that the positions determined by the IGS-RTS method (which is the method under evaluation) agreed with those of static GNSS method at the 0.060m (6cm) level for all the GCPs except for CE and BN (it should be noted however, that these two points had low ambiguity resolution (55.6% and 36.4% respectively) in the static GNSS method). Again, except for CE and BN, the heights given by the IGS-RTS and static GNSS methods agreed at below 0.030m (3cm) level (Table 4.6 and Fig 4.3).

(El-Diasty and Elsobeiey, 2015) [3] generated 2-Dimension (2-D) root mean square (RMS) difference between IGS-RTS (denoted as PPP) and RTK GPS (denoted as RTK) at 39% and 95% as follows:

$$RMS_{39\%}^{2D} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{N}_{PPP}-\hat{N}_{RTK})_i^2+(\hat{E}_{PPP}-\hat{E}_{RTK})_i^2}{n}} \qquad (4.2)$$

$$RMS_{95\%}^{2D} = 2.44\, RMS_{39\%}^{2D} \qquad (4.3)$$

Where, $(\hat{N}_{PPP}, \hat{E}_{PPP})$ and $(\hat{N}_{RTK}, \hat{E}_{RTK})$ are northings and eastings estimated from IGS-RTS and RTKdata respectively; and n is the total number of stations.

Applying equations (4.2) and (4.3) to all stations in Table 4.6 yield 3-D RMS of 0.135m and 0.329m at 39% and 95% confidence limits respectively. The corresponding 2-D RMS are 0.12m and 0.292m at 39% and 95% respectively.

When however, station BN is removed because of its low percentage ambiguity resolution (36.4%), the 3D RMS values reduce to 0.072m and 0.176m at 39% and 95% limits respectively. The corresponding 2D RMS values become 0.039m and 0.095m respectively.

Field Speed: All the field observations for the static GNSS method lasted for at least two hours at each GCP. On the other hand, the field observations for the IGS-RTS method lasted for less than 32 minutes at each GCP (Table 4.3). At 5cm agreement with the static method, we are inclined to opine that the IGS-RTS method has good speed.

Availability: We had 100% availability of streamed data during the more than four hours of observation. This may not be long enough for a conclusive assessment of the availability of data, but it looks better than the present situation (in Nigeria for instance) where there are sometimes data outages from Continuously Operating Reference Stations (CORS) for more than two weeks.

5. Conclusion and Recommendations

To draw our conclusion, we decided to exclude the results obtained for the BN ground control point because of its low ambiguity resolution (36.4%). Thus, we conclude that IGS-RTS method is compatible with the GNSS static method in 2-dimensional horizontal accuracy (RMS) at the level of 0.039m at 39% confidence limit and 0.095m at 95% limit. They are also compatible in height at the level of 0.121m at 95% confidence limit (if BN is removed). The GNSS static method is usually applied for 1st – and 2nd –order control establishment. With the level of agreement achieved by the IGS-RTS method, it can be concluded that the method will be useful to surveyors in Enugu, Nigeria for cadastral, GIS (Geographic Information System) and engineering surveying. It will also be useful for second-order topographic mapping (provided a good geoid model is available). Its availability and speed-of-usage will save costs for surveyors as they will cover large areas within a short period. It is also important to recommend that results for stations whose positions are determined with low ambiguity resolution (i.e. below 50%) should be rejected and re-observed.

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