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ORIGINAL RESEARCH

Determination of position coordinates of the new active CORS in Ghana

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Abstract

Global Navigation Satellite System (GNSS) technologies provide services and applications in a wide range of areas, including survey and mapping, transportation, precision agriculture, urban planning, smart mobility and smart city management, to name a few. Most of these applications rely on real-time kinematic (RTK) technology, which is typically supported by a network of continuously operating reference stations (CORS). In order to improve GNSS applications in Ghana, eight new CORS were established by the Licensed Surveyors Association of Ghana (LiSAG) in 2019 known as LiSAGNet. Accurate and precise positions of the LiSAGNet are, however, very critical for GNSS applications. Thus, the aim of this study is to determine accurate three-dimensional (3D) coordinates of the LiSAGNet using Network-based and Precise Point Positioning (PPP) techniques based on the International Terrestrial Reference Frame (ITRF). Positions of the new CORS were computed from data for 11 consecutive days using gLAB software v5.4.1 in PPP mode and the Canadian Spatial Reference System PPP (CSRS-PPP) online services as a check. Position solutions from both gLAB and CSRS-PPP were compared, which yielded coordinates variability of 0.001 m, 0.003 m and 0.029 m in the northings (N), eastings (E) and up (U) directions respectively and were therefore accepted as the final coordinates of the LiSAGNet. Positions from the PPP and Network-based techniques were also compared to determine consistencies or otherwise in the coordinates of the LiSAGNet. The study concluded that positions of LiSAGNet showed more consistency when determined by Network-based technique than when determined by PPP technique.

Keywords: GNSS, CORS, PPP, Coordinates Variability

Introduction

Geospatial data is critical for organized societies in all aspects of spatial planning, design, and implementation, as well as the efficient use of resources (Kamil *et al.,* 2010). Global Navigation Satellite Systems (GNSS), e.g., the US Global Positioning System (GPS), the Russian GLObalnaya NAvigatsionnaya Sputnikovaya Sistema (GLONASS), the Chinese's BeiDou Navigation Satellite System (BDS), and the European Union's Satellite Navigation System (GALILEO), which were originally designed for military purposes, now provide all-weather, all-time (24hrs) precise and accurate three-dimensional (3D) Positioning, Navigation, and Timing (PNT) information to all kinds of users anywhere on the surface of the earth (Hofmann-Wellenhof *et al.,* 2008; Kaplan and Hegarty, 2017). This capability has resulted in an increase in demand for reliable and cost-effective PNT solutions, which has necessitated the development of innovative technologies and value-added services and applications with GNSS for socio-economic developments. Being integrated into every aspect of everyday life, GNSS has become a vital and cost-effective tool for promoting sustainable economic growth (Poku-Gyamfi, 2009). GNSS technologies have evolved over the years into multifaceted services and applications in a wide range of areas, such as survey and mapping, transportation, precision agriculture, urban planning, smart mobility and smart cities management, to mention but a few. According to Minetto *et al.* (2020), "a sustainable economy enables cities to make long-term investments necessary to build and maintain adequate infrastructure so as to provide effective services, develop an open social environment for citizens, and foster and support business activities without compromising the natural environment".

Geospatial or geolocation and navigation-related technologies play a key role in urban planning and smart city services. According to Petcovici & Stroulia (2016), precise geolocation data provides the requisite solutions to every smart city. Geospatial technologies or Location-Based Services (LBS) are applicable in the area of geo-coding, traffic management, access control, energy efficiency, geofencing, city marketing, autonomous mobility, real estate development, public health and safety, crime prevention, and event management (Tadic *et al.,* 2016; Li *et al.,* 2013; Usman *et al.,* 2018; Minetto *et al.,* 2020). To satisfy the needs of any smart city solution, GNSS PNT solutions are one of the key enablers of such services that can provide high-precision positioning accuracy, heading, and even timing performance.

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In the context of precision agriculture (defined as the use of diverse technologies and solutions to increase farm efficiency, improve crop yield, boost agricultural productivity, minimize environmental impact, and contribute to addressing societal challenges), GNSS technology is once again one of the enabling technologies that can improve farm management and precision agriculture efficacy. Farm machinery guidance, automatic steering, variable rate application, yield monitoring, biomass monitoring, soil condition monitoring, livestock tracking, and agri-logistic applications such as farm machinery monitoring and asset management, geo-traceability, field delineation, and many more are some of the most important GNSS-enabled applications in precision agriculture.

The above-mentioned applications rely on GNSS observables provided by Continuously Operating Reference Stations (CORS) installations. In order to fully exploit the ever-growing potential of GNSS in providing maps and other spatial information for socio-economic development in Ghana, CORS networks or infrastructure are required (Erickson and Widmar, 2015). CORS are permanent GNSS stations which continually log and distribute GNSS observations to meet a variety of user needs. CORS networks were originally designed for geodetic and geophysical purposes, but they are today used as positioning infrastructure for a wide range of applications mentioned above. The use of accurate and precise positions of GNSS CORS is very crucial for enhancing services such as transportation, urban planning, precision agriculture, smart mobility and smart city management as previously mentioned for national development. These services largely require the application of Real-Time Kinematic (RTK) technique, which is typically supported by a network of GNSS CORS. It is therefore imperative to expand the CORS network in Ghana in order to improve RTK services, thereby promoting survey and mapping, transportation, precision agriculture, housing, and smart city management for national development.

For this purpose and to improve GNSS applications, the Licensed Surveyors Association of Ghana (LISAG) established eight CORS in Ghana in 2019 called LiSAGNet (Poku–Gyamfi et al., 2021). The primary goal of LiSAGNet was to support cadastral mapping, virtual reference services (VRS) and RTK services in Ghana. The positions of LiSAGNet were published by the Survey and Mapping Division (SMD) of the Lands Commission of Ghana based on War Office Ellipsoid in December 2020 with reference number M01/13/1/4. As a result, users could not access the positions of LiSAGNet directly in International Terrestrial Reference Frame (ITRF) unless coordinates transformations were performed. Furthermore, users continue to experience coordinates inconsistencies when different reference-CORS were used in fixing the same boundary points for cadastral purposes. The need to recompute more consistent and homogeneous coordinates for the new active CORS based on ITRF became apparent. The ITRF was adopted as the standard and most precise reference frame for positioning applications by the International Union of Geodesists and Geophysicists (IUGG) in 2015. The IUGG subsequently admonished participant countries to link their local coordinates systems to the ITRF. This study was, therefore, designed to address the above-mentioned issues in which accurate three-dimensional (3D) coordinates of the LiSAGNet were determined by Precise Point Positioning (PPP) and Network-based techniques based on ITRF-2014 version.

Background to Geodetic Control Points in Ghana

The geodetic control points were established as far back in the 1920s by the British (Ayer and Fosu, 2008). They were marked by "A" type pillars and connected by primary traverses and triangulation techniques. The survey, also known as Gold Coast Survey, took several years but was completed in 1929 (Ayer and Fosu, 2008). In view of the level of technology at the time, conventional methods such as trilateration, triangulation, traverses, and astronomical observations for position fixing were employed in the establishments of the frame of reference networks. The conventional methods could not cover very large areas at a go, due to the nature of the terrain. As a result, the country was divided into zones for purposes of surveying and mapping (Ziggah *et al.,* 2017). The terrain of the southern parts of Ghana is characterized by mountains and hills, whereas the terrains in the northern parts are averagely flat. In view of this, triangulation technique was often employed for most parts of the southern Ghana with only few traverses used in some non-hilly areas of the central and western Ghana. The northern Ghana was largely surveyed by method of traverses commonly called the T-Traverses. Obviously, the Ghana geodetic network was established by a combination of traverses and triangulation methods. Each of these traverses and triangulation blocks was adjusted separately, but not in a single harmonized adjustment. Consequently, departing from and closing on ground control points which were established by different traverses or triangulations blocks resulted in coordinates disagreements. This situation continues to persist in Ghana and its impacts on engineering works as well as cadastral mapping are enormous. For instance, land boundary disputes often result from such coordinates disparities. Unless and until the different traverses and triangulation blocks are adjusted in a single adjustment loop, coordinates consistencies and homogeneity cannot be achieved in Ghana.

Before the execution of the survey, topographical maps were produced in May, 1924 for use in the actual reconnaissance surveys. During reconnaissance, several figures were formed by selecting suitable ground points on hills and ridges in the southern Ghana. Traverse networks were used in the northern Ghana and other low-lying regions. Clearing of survey lines was done by the clearing parties whilst chaining of baselines was carried out by special survey parties. After a successful reconnaissance, base measurements were carried out in each of the figures so formed. The first base was selected between Akuse and Odumasi in the Eastern Province, now called the Eastern Region. Distances and angles were measured using tapes and theodolites. Figural adjustments of triangulation and traverse networks to satisfy geometrical conditions and the closure between the bases could not be carried out in one operation. The practice of breaking the chains into suitable figures for adjustment was adopted. Astronomical observations and computation of coordinates were done earlier and therefore, it was easier to transfer positions to adjusted figures and networks. The figure of the earth adopted for the Gold Coast (Ghana) was one suggested by the War Office of the British Army; hence it was named as the War Office Ellipsoid, 1926. The elements of the War Office Datum are: - $a = 20{,}926{,}201.2257$ feet; $b = 20{,}855{,}504.6001$ feet; $f = (a-b)/a = 1/296$; log. (feet/metres) = 9.484 014 544 967. Where a is semi-major axis, b is semi-minor axis and f is inverse flattening of the reference ellipsoid.

In June, 1904, observations for latitude were taken by Sir F. G. Guggisberg (Governor of the Gold Coast Colony), from a survey pillar located in the compound of the house of the Secretary for Native Affairs in Accra (Ayer and Fosu, 2008). Using a zenith telescope, fifteen pairs of stars were observed giving a final probable error of 0.360". This point was later connected by traverse, to the Gold Coast Survey beacon, No. G.C.S. 547 in Accra. The longitude of Accra was determined by the exchange of telegraphic signals with Cape Town in November and December, 1904, and the resulting longitude of G.C.S. 547 obtained. Pillar G.C.S. 547 was connected to the pillar at Leigon, No. G.C.S. 121, by means of triangulation, and the resulting values of the Leigon pillar were adopted as the basic latitude and longitude for Ghana. Subsequent determination of latitude and longitude of points throughout the country was carried out by connecting to the Leigon pillar by triangulation. For purposes of cadastral mapping, geographical coordinates were inconvenient, and in their place, plane rectangular coordinates on the transverse Mercator projection were adopted. The whole country was placed on the same origin, the central meridian being 10 W and the origin of the X coordinates 40 40' N. In order to avoid negative coordinates, 900,000 was added to all Y coordinates and the maximum scale error was reduced by 1/4000 so that the scale error nowhere exceeded this value except on the extreme edges of the country. The formulae used in the conversion of geographical into country coordinates and the computation of convergence can be found in (Ayer and Fosu, 2008).

Materials and Methods

The new active CORS in Ghana

The new active CORS also called LiSAGNet, currently consists of eight stations out of a proposed twenty-seven stations across Ghana (Poku – Gyamfi *et al.,* 2021). Accra Spintex and Adum Kumasi stations were mounted with Leica GR50 dual frequency receivers with LEIAR10 NONE antennas. The rest of the stations in Tarkwa, Koforidua, Takoradi, Winneba, Oda and Ho were mounted with Leica GRX1200GGPRO dual frequency receivers with LEIAS10 NONE antennas. The antenna monuments were built above the main buildings housing the receivers in order to reduce obstructions and minimize GNSS signal multipath effects (Figure 1). Lightning arrestors were also installed at each station to mitigate impacts of thunderstorms. These are state-of-the-art GNSS equipment for contemporary surveying and mapping services.

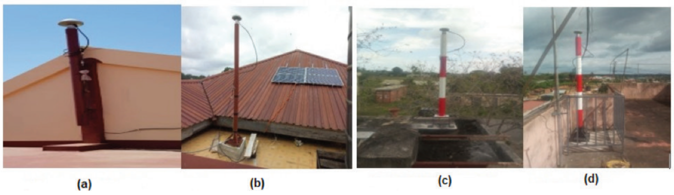

Figure 1 (a) Antenna mount of Spintex CORS, (b) Antenna mount of Adum CORS, (c) Antenna mount of Tarkwa CORS and (d) Antenna mount of Oda CORS.

The data centre is located at Spintex area in Accra where the first CORS, LSA1 is mounted. Data is stored virtually using cloud data storage. LiSAGNet uses Leica Spider software for data quality checks, sampling and conversion.

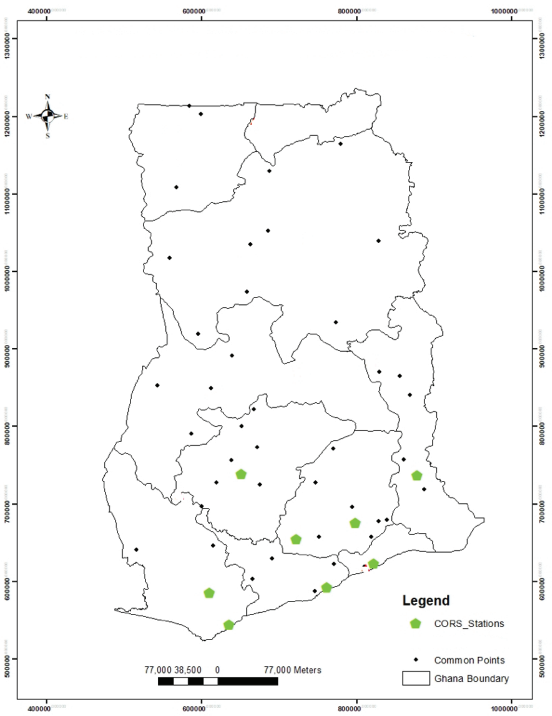

Figure 2 Map of Ghana showing distribution of active CORS of LiSAGNet

LiSAGNet uses Leica Spider software for data quality checks, sampling and conversion. LiSAG Management System (LMS) software is currently being developed to track online usage and transactions online. The expansion of the LiSAGNet is demand-driven, hence, all the eight CORS were established in the southern parts of Ghana where land surveying and positioning activities are on high demand. Distribution of LiSAGNet CORS together with the proposed nineteen CORS across Ghana is presented in Figure 2. The initial objective of LiSAGNet was to provide static post-processing services for cadastral mapping in Ghana. Additional products and services intended to be provided by LiSAGNet include Real Time Kinematics (RTK), Virtual Reference Services (VRS) and Network RTK (NRTK) services. These network services intended to use Networked Transport Radio Technical Commission for Maritime services (RTCM) via Internet Protocol, NTRIP.

Methodology

The methods and data processing used in this study have been presented in Figure 3.

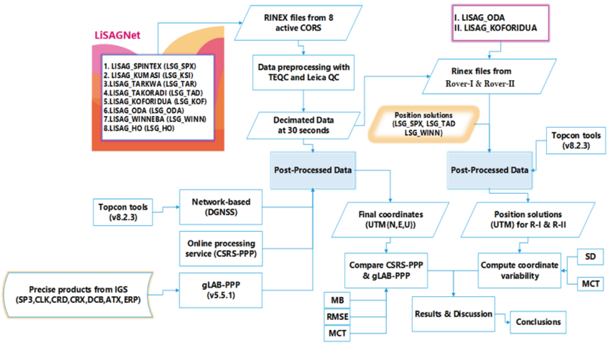

Figure 3 Outline of the study

Precise point positioning (PPP) algorithms

Both CSRS-PPP and gLAB software computed positions of all the eight new CORS in PPP mode using simplified equations (1) – (4) (Gao *et al.,* 2002; Yigit *et al.,* 2014; Mohammed *et al.,* 2016) in accordance with similar studies (Andritsanos *et al.,* 2016; Akpınar and Aykut, 2017; Soni *et al.,* 2020

$$P_1 = \rho + c(dt_r - dt^s) + T + I_1 + cd_{rp1} - 2.546c.DCB_{p1-p2} + dm_{p1} + e_1 \text{ ....[1]}$$

$$P_2 = \rho + c(dt_r - dt^s) + T + I_2 + cd_{rp2} - 2.546c.DCB_{p1-p2} + dm_{p2} + e_2 \text{ ....[2]}$$

$$\gamma_1\varphi_1 = \rho + c(dtr_r - dt) + T - I_1 + \lambda_1 N_1 + c\left(\partial_{r1} + \partial_1^s - 2.546_{p1}^s + 1.546_{p2}^s\right) + \partial_{m1} + \varepsilon_1 \text{ ......[3]}$$

$$\gamma_1\varphi_1 = \rho + c(dtr_r - dt) + T - I_2 + \lambda_2 N_2 + c\left(\partial_{r2} + \partial_2^s - 2.546_{p1}^s + 1.546_{p2}^s\right) + \partial_{m1} + \varepsilon_2 \text{ ..... [4]}$$

where P_1, P_2 are pseudo range measurements, φ_1, φ_2 are carrier phase measurements and λ_1, λ_2 are wave length for L1 and L2 signals respectively; ρ is true geometric range between satellite and receiver antennal phase centre; c is the speed of light in vacuum; dt_r , dt^s are receiver and satellite clock errors; DCB is satellite differential code bias; T is tropospheric delay in range units and I_1, I_2 are ionospheric delay in range units on L1 and L2 respectively; $\partial_{r1}, \partial_1^s, \partial_{r2}, \partial_2^s$ are frequency depend carrier phase hardware delay for receiver and satellite; $d_{p1}^s, d_{p2}^s, d_{rp1}, d_{rp2}$ are code hardware delay for satellite and receiver; dm_{p1}, dm_{p2} are code multipath effect; $\partial_{m1}, \partial_{m2}$ are carrier phase multipath effect; $e_1, e_2, \varepsilon_1, \varepsilon_2$ are unmodelled error sources; N_1, N_2 are integer ambiguity parameters for L1 and L2 respectively.

Description of data

Receiver Independent Exchange Format (RINEX) data files for 11 consecutive days were downloaded from LiSAGNet covering DoY 71 to DoY 82 2020. The data were recorded at 10-degree elevation mask angle and sampled at 30s rate on each day.

Selection of software

The use of PPP for establishing active CORS has been presented in a number of articles, including (El-Hattab, 2014; Rabah *et al.,* 2016). According to (Mageed 2015; Hamidi and Javadi, 2017; Andritsanos *et al.,* 2016). Scientific software such as gLAB and CSRS-PPP, an online post-processing service, perform reliably well when computing positions in precise point positioning (PPP) mode. Consequently, gLAB software was used for post-processing positions of the new active CORS in PPP mode.

Post processing data

Before post-processing, the data was checked against systematic errors using Leica QC version 2.2 and Translation, Editing, and Quality Check (TEQC) software. Cycle slips, percentage of data completeness and multipath metrics were as well assessed to ensure compliance with IGS standards (Zuo, *et al.,* 2019; Johnston *et al.,* 2017). For purposes of post-processing, the GNSS data were sent to the CSRS-PPP online service and the coordinates of each CORS were calculated. The same data were also processed using gLAB software in PPP mode and the two processing solutions were compared using the CSRS-PPP solutions as reference. Finally, the data were processed in a network-based technique using LISAG_KUMASI CORS as reference by Topcon Tools v8.2.3 as shown in Figure 4.

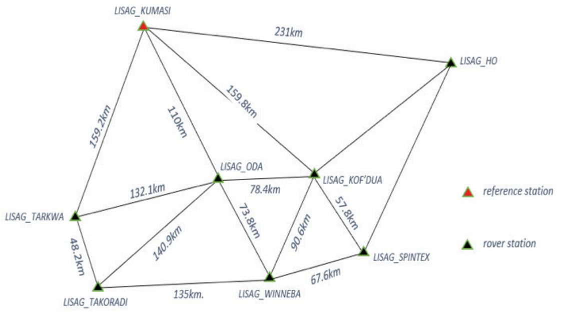

Figure 4 Main loop used in computing positions of CORS in the LiSAGNet

Experimental test

Experimental field network was designed and carried out to examine consistency or otherwise in the positions of the LiSAGNet as shown in Figure 5. Post-processing was carried out using Topcon Tools v8.2.3 in differential mode.

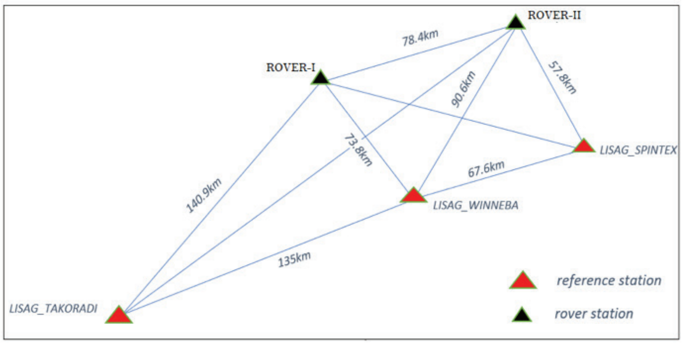

Figure 5 Experimental test network

Coordinates of the LiSAGNet based on PPP technique were used as reference input to compute the positions of ROVER-I and ROVER-II, keeping LISAG_SPINTEX, LISAG_WINNEBA and LISAG_TAKORADI as reference stations in separate campaigns. The mean positions of ROVER-I and ROVER-II were tabulated. Secondly, coordinates of the LiSAGNet based on the Network-based technique were used as reference input to compute the positions of ROVER-I and ROVER-II, keeping LISAG_SPINTEX, LISAG_WINNEBA and LISAG_TAKORADI as reference stations in separate campaigns. The mean positions of ROVER-I and ROVER-II were tabulated. Average coordinate variability of ROVER-I and ROVER-II were computed and tabulated for onward discussions.

Statistical Evaluation

This section aims to evaluate the precision or variability of the Network-based processing technique to that of the PPP technique and, also, compares gLAB processing solutions to CSRS-PPP service solutions as previously indicated. To achieve this, the standard deviation (SD), mean bias (MB), and root mean squared error (RMSE) metrics were respectively used. The computation of these metrics is based on Equations (5), (6) and (7).

$$SD = \sqrt{\frac{1}{N-1}\sum_{i-1}^{N}(x_i - \mu)^2} \quad (5)$$

$$MB = \frac{1}{N}\sum_{i-1}^{N} POS_{gLAB} - POS_{CSRS-PPP} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i-1}^{N}(POS_{gLAB} - POS_{CSRS-PPP}} \quad (7)$$

where μ is the mean value, xi is i-th position value, N is the total number of points or observations.

To further investigate if the difference in the mean values between gLAB-PPP and CSRS-PPP processing solutions is statistically significant at 5 % significant level, a non-parametric multiple comparison test (MCT) was conducted using MATLAB programming language. A similar test was also conducted to test whether the differences in the mean values of the Network-based and PPP processing techniques are significant. The Null and Alternate hypothesis (H_o and H_1) tests are stated as follows:

H_o: There is no significant variation in the coordinates of the gLAB and CSRS-PPP processing solutions and Network-based and PPP processing techniques.

H_1: There is significant variation in the coordinates of the gLAB and CSRS-PPP processing solutions and Network-based and PPP processing techniques.

Results

In this section, the positions of the active CORS from various post-processing schemes were presented and related to this study. For purposes of this discussion, the positions of the LiSAGNet computed by gLAB software shall be referred to as gLAB-coordinates. Similarly, positions computed in the Network-based technique shall be referred to as Network-coordinates. Positions of the LiSAGNet computed by the PPP and Network-based positioning techniques were presented in Tables 1 and 2.

Table 1 PPP solutions from CSRS-PPP and gLAB based on ITRF2014 datum epoch 2019.7768

SOURCE:		CSRS			gLAB		
Location	Pillar ID	N	E	U	N	E	U
ACCRA	LISAG_SPINTEX	623516.995	822654.950	75.578	623516.995	822654.941	75.665
KUMASI	LISAG_KUMASI	739465.093	651958.267	308.325	739465.087	651958.260	308.416
TARKWA	LISAG_TARKWA	585660.945	610803.861	108.268	585660.946	610803.846	108.367
TAKORADI	LISAG_TAKORADI	544552.504	635925.766	43.622	544552.498	635925.766	43.638
KOFORIDUA	LISAG_KOFORIDUA	676031.927	798599.206	222.389	676031.928	798599.207	222.434
ODA	LISAG_ODA	655451.549	722919.835	164.546	655451.545	722919.840	164.599
WINNEBA	LISAG-WINNEBA	593031.483	762295.979	44.906	593031.481	762295.986	44.970
HO	LISAG_HO	731270.019	219176.857	232.517	731270.019	219176.857	232.517

Table 2 Positions of LiSAGNet by network-based technique based on ITRF2014 epoch 2019.7768

SOURCE:		Network-based Technique		
Location	Pillar ID	N (m)	E (m)	U (m)
ACCRA	LISAG SPINTEX	623516.992	822654.949	75.570
KUMASI	LISAG_KUMASI	739465.090	651958.268	308.327
TARKWA	LISAG TARKWA	585660.942	610803.862	108.269
TAKORADI	LISAG_TAKORADI	544552.500	635925.774	43.570
KOFORIDUA	LISAG KOFORIDUA	676031.922	798599.215	222.334
ODA	LISAG ODA	655451.544	722919.842	164.490
WINNEBA	LISAG-WINNEBA	762295.986	593031.479	44.847
HO	LISAG HO	731270.019	219177.661	232.517

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The experimental test results in UTM based on ITRF 2014 were presented in table 3 and 4 using gLAB-PPP coordinates and Network-based coordinates as reference input respectively. In table 3, the positions of ROVER-I and ROVER-II were obtained when input coordinates of reference- CORS (LISAG_SPINTEX, LISAG_WINNEBA and LISAG_TAKORADI) were based on PPP technique. In table 4, the positions of ROVER-I and ROVER-II were obtained when input coordinates of reference-CORS (LISAG_SPINTEX, LISAG_WINNEBA and LISAG_TAKORADI) were based on Network-based technique.

Table 3 Positions of rover stations using gLAB-PPP coordinates as reference input

Source REFERENCE STATIONS	ROVER STATION	Northings (m)	Eastings (m)	Up (m)
LISAG_SPINTEX	ROVER-I	655451.829	722919.170	165.814
LISAG_WINNEBA	ROVER-I	655452.076	722919.298	166.621
LISAG_TAKORADI	ROVER-I	655452.471	722920.231	167.362
LISAG_SPINTEX	ROVER-II	676032.378	798598.943	223.926
LISAG_WINNEBA	ROVER-II	676032.768	798599.412	224.968
LISAG_TAKORADI	ROVER-II	676032.995	798599.814	225.579

Table 4 Positions of rover stations using network coordinates as reference input.

Source REFERENCE STATIONS	ROVER STATION	Northings (m)	Eastings (m)	Up (m)
LISAG_SPINTEX	ROVER-I	655450.859	722920.898	161.808
LISAG_WINNEBA	ROVER-I	655450.855	722920.801	161.877
LISAG_TAKORADI	ROVER-I	655450.812	722920.877	161.875
LISAG_SPINTEX	ROVER-II	676031.477	798600.510	219.847
LISAG_WINNEBA	ROVER-II	676031.421	798600.551	219.968
LISAG_TAKORADI	ROVER-II	676031.372	798600.569	219.973

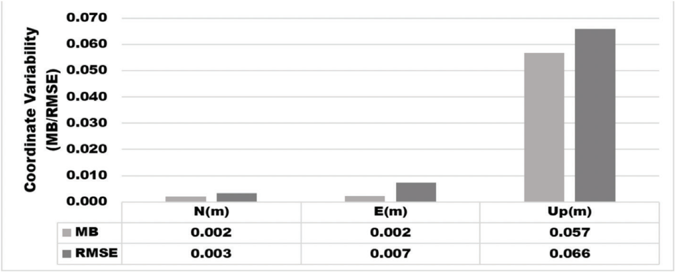

Figure 6 Mean coordinates variability of rover positions using different coordinates as reference input

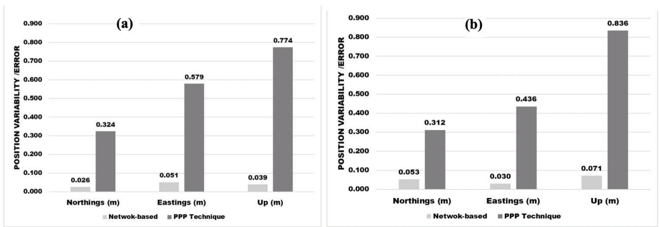

Figure 7 (a) Mean coordinates variability of ROVER-I position using network-based and PPP coordinates as reference input and (b) Mean coordinates variability of ROVER-II positions using network-based and PPP coordinates as reference input

Discussion

The CSRS-PPP solutions were compared with gLAB-PPP solutions and the results were presented in Table 4. The aim was to affirm the gLAB-PPP solutions, hence, the comparison with a world standard postprocessing service such as the CSRS-PPP solutions. The average coordinates variability in the northings (N), eastings (E) and Up directions were 0.003m, 0.006m and 0.065m respectively, indicating very high congruences in both solutions. Further comparison between Network-based solutions and gLAB-PPP solutions yielded average coordinates variability of 0.002m, 0.006m and 0.085m respectively in N, E and U directions indicating very high congruences in both solutions. These results were similar to those in (El-Hattab, 2014; Rabah et al., 2016; El-Tokhey et al., 2018). El-Hattab in his article, obtained coordinates variability of 0.003m in both N, E and 0.010m in the U directions and recommended the use of PPP approach for establishment of municipal CORS in the Middle East. Figure 8 also showed that CSRS-PPP and gLAB-PPP solutions were highly comparable.

To measure the homogeneity in the positions of the rover stations, reference is made to Figure 6. The mean bias (MB) and root mean square error (RMSE) for the coordinate differences in the positions of ROVER-I and ROVER-II as given by different reference CORS presented in Figure 6 are in millimetres. This indicates the quality of the positions of the reference CORS as determined by the network-based technique in this study.

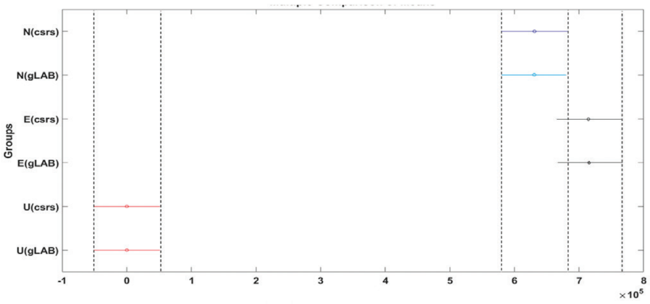

Figure 8 Multiple comparison of group means for CSRS-PPP & gLAB-PPP

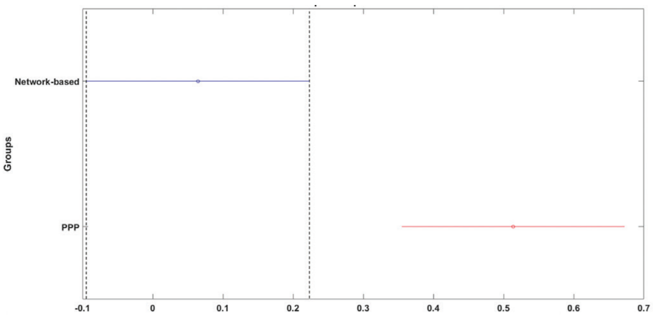

Figure 9 Multiple comparison of group means for network-based & PPP techniques

In checking the consistencies or otherwise of the positions of the new active CORS, references were made to Figure 7(a) and 7(b). In the first scenario, where the positions of ROVER-I and ROVER-II were fixed by reference-CORS based on PPP technique, the mean coordinates differences in the position of ROVER-I were 0.324m, 0.579m and 0.774m and that of ROVER-II were 0.312m, 0.436m, and 0.836m in the N, E and U directions respectively as shown in Figure 7(a) and 7(b). The coordinate differences in the positions of ROVER-I and ROVER-II were indications of inconsistencies in the coordinates of the reference-CORS. In this case, larger coordinate differences in the ROVER positions indicated greater coordinates inconsistencies in the positions of the reference-CORS. The inconsistencies could be attributed to the positions of the reference CORS being computed by autonomous PPP mode. For instance, even though the mean coordinates variability between solutions of Network-based and gLAB-PPP techniques were 0.002m, 0.006mand 0.085m respectively in N, E and U directions (indicating very high congruences) yet, reference-CORS computed in Network-based techniques showed greater internal consistencies than their counterparts in gLAB-PPP techniques. This indicates that, even though PPP solutions showed very high congruences with solutions from Network-based techniques, they exhibit high internal coordinates inconsistencies.

In the second scenario, the positions of ROVER-I and ROVER-II were fixed by the same reference CORS whose reference input coordinates were obtained by Network-based solutions. This time round, average coordinates differences in the position of ROVER-I were 0.026m, 0.051m and 0.039m and that of ROVER-II were 0.053m, 0.030m and 0.071m in the N, E and U directions respectively. The findings were that, in using coordinates input of the reference-CORS computed on the network-based technique, the average coordinates differences in the positions of ROVER-I and ROVER-II improved significantly. For instance, the average coordinates differences in the position of ROVER-I were 0.428m, 0.708m and 1.032m when input coordinates of the reference-CORS were based on PPP technique, but were significantly reduced to 0.031m, 0.065m and 0.046m when input coordinates of the reference-CORS were computed on Network-based technique as shown in Figure 7(a). Similarly, the average coordinates difference in the position of ROVER-II were 0.411m, 0.581m and 1.102m when input coordinates of the reference-CORS were based on PPP technique, but were significantly reduced to 0.053m, 0.030m and 0.071m when input coordinates of the reference-CORS were based on Network-based technique as shown in Figure 7(b). The findings indicated that coordinates of reference-CORS were more consistent when their positions were computed in a Network-based technique than when computed by PPP technique. The reasons why coordinates of the reference-CORS were more consistent when computed by Network-based technique than when computed by PPP technique can be attributed to the architecture of both techniques. For instance, the PPP technique uses undifferenced, dual-frequency, pseudo range and carrier-phase observations along with precise satellite orbit and clock products, to fix positions in a standalone manner using a specified model to correct for systematic effects (Kouba et al., 2017). On the other hand, the Network-based technique uses all the information used by PPP technique to fix positions simultaneously using a common reference station in a closed geometric figure, such that positional errors can be adjusted within the network (Prochniewicz et al., 2020; Marila et al., 2016). The positions of CORS which were fixed in such a network will remain in sympathy or agreement when their coordinates were used to fix position of a common rover. Consequently, in a standalone positioning, the positional errors at the individual CORS sites are not often adjusted in network, hence, there would be no agreement when their coordinates were used to fix position of a common rover.

Again, the results of the MCT are shown in Figures 8 and 9. The MCT is used to determine which pairs of means are significantly different, and which pairs are not. Figures 8 and 9 provide an interactive graph with each group mean represented by a symbol (small circle) and a comparison interval or bar represented by a line extending from the symbol (horizontal line) as shown in Figures 8 and 9. The means of Two groups are significantly different if their intervals are disjoint and significantly indifferent if their intervals overlap or intersect. It is obvious from Figure 8 that the coordinate solutions from CSRS-PPP are not significantly different from gLAB-PPP at 95% confidence level in terms of N, E and U. For a selected group (e.g., Network-based in Figure 9), the comparison bar is highlighted blue and all other groups which are significantly different are highlighted red. The bars for the groups which are not significantly different are highlighted in grey. However, Figure 9 indicates that the mean of group 1 (coordinate solution from Network-based technique) highlighted in blue is significantly different from groups 2 (coordinate solution from PPP technique) at 5% significance level.

Conclusions and Recommendations

This study successfully determined position coordinates of the LiSAGNet using precise point positioning technique and Network-based technique based on ITRF 2014. Position coordinates of the LiSAGNet based on gLAB-PPP were comparable with position coordinates from CSRS-PPP online service. Position coordinates of reference-CORS as computed by Network-based technique had greater internal consistencies than Position coordinates of reference-CORS computed by PPP technique. It was recommended that positions of reference-CORS be computed in a network rather than single-baseline or autonomous solutions in order to ensure coordinates consistencies.

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Conflict of Interest Declarations

There is no conflict of interest in connection with this submitted article.

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