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EVALUATION OF GNSS LABORATORY SOFTWARE AND REAL TIME KINEMATIC LIBRARY FOR PROCESSING GNSS DATA

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Abstract

Geodesy applications demand comprehensive knowledge of Global Navigation Satellite System (GNSS) data and the associated processing software. Over time, several open software options have been employed for GNSS data processing. The software's accuracy is vital in the various fields where GNSS data finds applications. GNSS Laboratory software (G-LAB) and Real Time Kinematics Library (RTK-LIB) have become widely utilized for GNSS data processing due to their effectiveness and accessibility. In this study, we processed four months' data (August, October, November, and December) from four Continuous Operation reference stations (CORS) using G-Lab and RTK Lib in static Precise point positioning (PPP) mode. A comparative analysis was performed on the results obtained from both software. The statistical analysis indicates that RTK Lib outperformed G-Lab in data processing, RTK-Lab displays the least RMSE value of Eastings, Northings, and heights with differences in terms of RMSE of 1.750m, 0.538m, and 0.250 m for Eastings, Northings, and Height respectively. The results show that RTK-Lib software is more reliable for GNSS data processing. Future investigations should involve using one year or longer of data and considering more CORS stations to gain further insights.

***Keywords**: GNSS, Precise point positioning, G-Lab and RTK Lib software, CORS.*

1. Introduction

In contemporary times, various organizations, notably the International GNSS Service (IGS), have been providing researchers with precise satellite orbits and clock products for Geographical positioning system (GPS) and Global navigation satellite system (GLONASS) constellations. These products are made available through the IGS website free of charge and come with different levels of accuracy. In recent years, novel techniques utilising information from a single Geographical Navigation Satellite System (GNSS) receiver have been explored as an alternative to the conventional differential approach for developing these products. One such technique is Precise Point Positioning (PPP), which has garnered significant interest from academic and commercial communities in the last decade (Heroux *et al.,* 2001; Bako *et al.,* 2019).

PPP enables a single receiver's measurements to determine the longitude (X), latitude (Y), and height (Z) components, along with other parameters such as receiver clock error and extreme neutral delay in the atmosphere. During data processing, the method leverages accurate a-priori data, such as orbits and clock errors, leading to precise position coordinates. Besides positioning applications, PPP can be employed for various tasks, as its observation model accounts for signal inconsistencies and observation variations (Leandro *et al*., 2011).

Geodesy places significant emphasis on validating and verifying the obtained results. The primary goals include achieving consistent measurements under diverse environmental conditions, particularly concerning GNSS observations in permanent station setups. Additionally, for continental or regional networks, it is essential to incorporate data from all available space-based techniques to identify and mitigate systematic errors that may affect the outcomes. This comprehensive approach aims to enhance the reliability and accuracy of the total geodetic products. To achieve these objectives, it is crucial to consider various factors and techniques to ensure the integrity of the results. Software packages and processing strategies are implemented and compared (Boylan, 2016).

The GNSS is based on GPS principles, involving the transmission and reception of signals between satellites and receivers on Earth (Hofmann-Wellenhof *et al.,* 2012). However, GNSS employs a more significant number of satellites to achieve increased accuracy (Bako *et al.,* 2019). Over time, GNSS technology has evolved and found applications across various fields, enabling precise point positioning. With continuous advancements, GNSS has significantly improved position-fixing accuracy, achieving errors as low as a few centimetres, depending on the specific positioning technique. For instance, alongside the development of GPS, the GLONASS was also established, leading to improved global coverage by the mid-2000s. Other systems, such as the European Union's Galileo, India's NAVIC, and Japan's Quasi-Zenith satellite systems, have been developed and integrated into the GNSS network (Zerin and Rahman, 2018). GNSS observation is useful in establishing a geodetic control network for remote sensing applications (Bako *et al.,* 2020). The processing of GNSS data is fundamental to the implementation of differential systems for acquiring spatial data. Both open-source and commercial GNSS data processing software is designed with specific functionalities to meet their intended applications (Charles *et al.* 2022).

Users have witnessed numerous new opportunities regarding GNSS data processing methodology developments. Several organisations have established online GNSS storage services to cater to these needs. These services grant users unrestricted access to GNSS processing results. Users can submit their Receiver Independent Exchange (RINEX) data to the service providers, who then rapidly return the processed results, utilising the approximate location of the data collection.

Notable organisations offering these free services include the Permanent Array Center (SOPAC) at the University of California, the Department of Geoscience Australia, the National Geodetic Survey (NGS), the Division of Geodetic Survey (GSD) in Canada, and the Scripps Orbit and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (Johnston, 2017).

Researchers have conducted numerous studies to evaluate and asses the accuracy of open source software across diverse geographical regions. Significant contributions in this field include the research conducted by Charles *et al.* (2022), Vázquez-Ontiveros *et al*. (2023)

and Seddiki and Beldjilali (2022). These studies specifically focused on accuracy assessment of different software's used in processing GNSS data in specific regions
In a recent study conducted by Charles *et al.* (2022), an assessment of GNSS software for the Survey and Mapping Division (SMD) of Ghana. To evaluate the performance of the developed software, GNSS data from two International GNSS Service (IGS) stations (BJCO and YKRO) were processed using GNSS Solution Software (GGS) and compared against results obtained from three commercial software packages GSS, Spectrum Survey Software (SSS), and Leica Geo Office (LGO). The positional accuracy of GGS was found to be superior to that of the other three commercial software solutions, achieving sub-meter accuracy Charles *et al.* (2022), In a separate study conducted by Vázquez-Ontiveros *et al.* (2023), an evaluation and analysis of the accuracy of open-source software and online services for PPP processing in static mode. The findings indicate that daily solutions for the East (E), North (N), and Up (U) components, derived from ten open-source software programs and five free online PPP services, can achieve millimeter-level precision at certain stations. Among the open-source software evaluated, PRIDE-PPPAR exhibited the highest accuracy, with Root Mean Square Error (RMSE) values of 5.52 mm, 5.40 mm, and 6.79 mm for the E, N, and U components, respectively. Conversely, among the online PPP services, APPS and CSRS-PPP provided the most precise results, yielding RMSE values below 12 mm for all three components. The comparable performance of open-source software and online PPP services in both horizontal and vertical positioning suggests that these tools can be reliably employed for static-mode PPP processing without compromising measurement accuracy.
Finally, Seddiki and Beldjilali (2022) conducted a performance evaluation of various GNSS positioning modes. Their study compared different GPS positioning techniques using RTKLIB, an open-source software package for GNSS data processing. The evaluated positioning modes included Single Point Positioning (SPP), PPP, Satellite-Based Augmentation System (SBAS), Differential GPS (DGPS), and RTK. Data for the analysis were collected using NetR9 receivers, which are multi-frequency, multi-constellation GNSS receivers capable of providing both carrier-phase and pseudorange measurements. The SPP method, the most basic positioning mode, offers an accuracy of approximately 5 meters but can be improved to about 1 meter with SBAS corrections, provided the system's coverage is available. DGPS also achieves 1-meter accuracy by utilizing a second receiver as a base station, though this increases operational costs. For applications requiring high-precision positioning, RTK and PPP techniques are employed to achieve centimeter-level accuracy. RTK relies on a base station and a rover receiver to perform real-time corrections, whereas PPP utilizes precise satellite orbit and clock corrections. However, real-time access to these corrections may be limited for some users Seddiki and Beldjilali (2022).
This study compares the accuracy achieved by two GNSS processing software, namely G-lab and RTK Lib when applied to processing Continuously Operating Reference Stations (CORS) data. The two software were used for this study because of their availability and are open-source (free) software. This paper is organized as follows: Section 2 describes the two software packages under study (G-LAB and RTK-Lib),

Section 3.0 outlines the CORS data used and the method applied in the research, and the results of comparing G-lab and RTK-lib were discussed in Section 4. Finally, we summarise the findings and conclusions of the study in Section 5.

2.0 The G-LAB and RTK-Lib Software for GNSS Data Analysis

2.1 GNSS laboratory software (G-LAB)

The GNSS-Lab Tool Suite (G-Lab) is a sophisticated software package for GNSS computation and analysis, offering dual-purpose functionality. Initially, G-Lab was limited to processing GPS data, but the latest version now supports differential GNSS and includes future module updates for Galileo and GLONASS expansion. The most recent release of G-Lab is version 5.4.0, dated 16 November 2018 (Ibáñez *et al.,* 2018). The software offers a range of capabilities, such as detecting cycle slips in GPS carrier phase measurements using three different methods, processing phase pseudo-range, and a carrier to identify specific frequencies available (for simulating RINEX data receivers with one frequency). It can also perform orbit information interpolation, correct the phase centre of the receiver, and edit Klobuchar, BeiDou, SBAS, or IONEX corrections. Additionally, G-Lab corrects solid tides and accounts for gravitational delay, a general relativistic consequence resulting from the gravity field gradient between transmitter and receiver.

G-Lab can decimate the RINEX input to enhance processing speed when high sampling rates are not required. Decimation is carried out after establishing cycle slips to fully utilize the input frequency information and validate the jump from the pseudo-range. The software addresses uneven sets of pseudo-range and carrier phase measurements in some receivers, which can lead to clock adjustments causing confusion and process errors for all satellites. G-Lab effectively detects and solves these issues by employing pre-alignment for carrier cycle pseudo-range measurements. This ensures a more direct and accurate comparison between the two types of measurements (Ibáñez *et al.,* 2018).

2.2 Real-Time Kinematics Library (RTK-LIB)

RTK-LIB is an open-source GNSS package known for its standard and accurate positioning capabilities (Thanh *et al.,* 2016). The software offers various GNSS positioning modes for real-time and post-processing applications, including single, relocating-baseline, differential GNSS, kinematic, static, fixed, PPP static, PPP-kinematic, and PPP-fixed modes. Furthermore, RTK-LIB supports multiple standard GNSS formats (Dyjak *et al.,* 2016).

3.0 Materials and Method

3.1 Materials

This study employed two distinct GNSS data processing software, RTK-Lib and G-Lab. Although several software packages exist for GNSS data processing such as those commercial software packages accompanying the basic GNSS receiver equipment, as well as other independent GNSS processing software such as Bernese, GIPSY and GAMIT GLOBIS for scientific data analysis, these are licensed and must be subscribed

to access. The choice of G-LAB and RTK-Lib was informed by their open-source accessibility and their wide application for scientific and commercial applications.
Therefore, the CORS data were processed using these two software packages. Four (4) months (August, October, November, and December) data from four (4) stations of the Nigerian GNSS network (NIGNET) was used in this study. The selected stations are ABUZ in Kaduna State, BKFP in Kebbi State, OSGF in Abuja, and ULAG in Lagos State; the distribution of the NIGNET stations across Nigeria is presented in Figure 1.

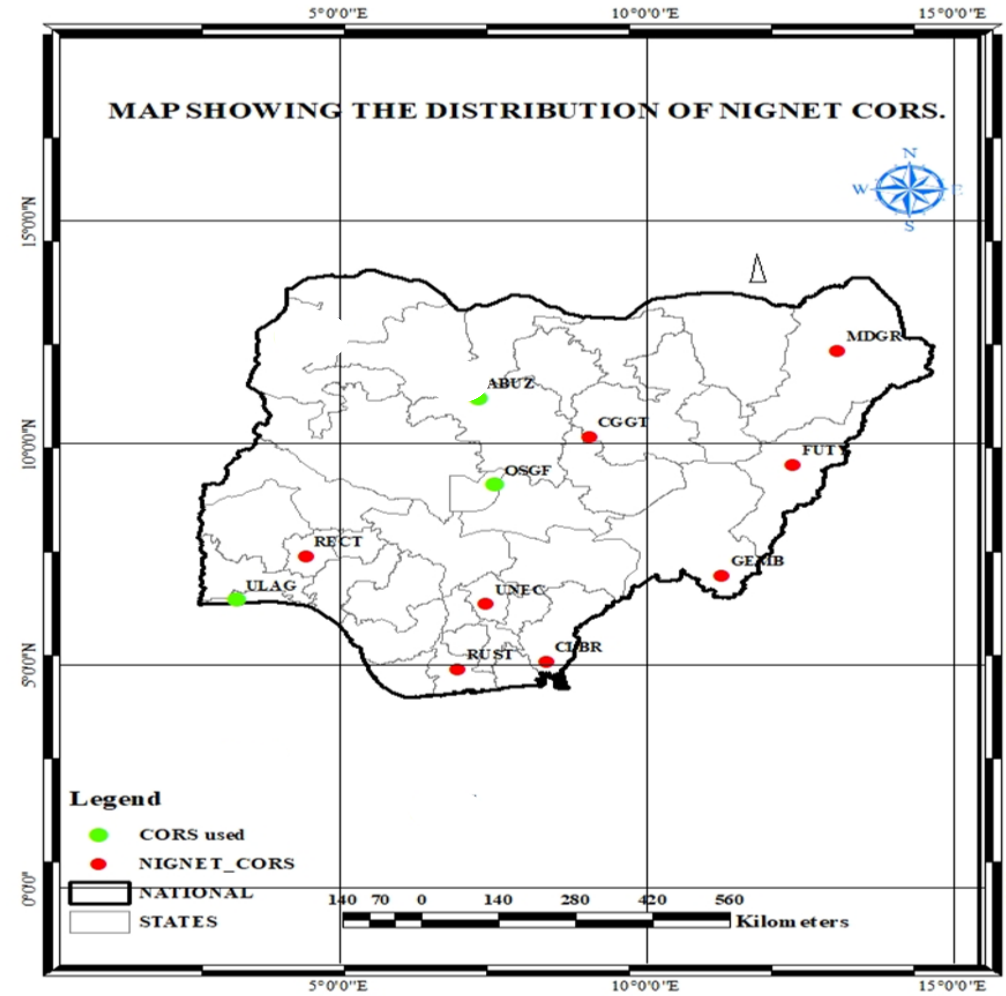

Figure 1: Distribution of CORS data used in this study (Adebomehin, 2016).

Twenty-four hours of data were collected for the fifth day of August, October, November, and December 2011 from the Nigerian GNSS network website (http://www.nignet.net/) which is used in this study. The data from NIGNET is stored in compact Receiver Independent Exchange (RINEX) format, provided in zipped files. The correction files, such as satellite orbit and clock files, were obtained to mitigate the corresponding satellite clock and orbit errors. These corrections are essential to account for minor inconsistencies in the satellite's atomic clock or drift in the satellite's rotation, which can significantly impact the accuracy of receiver positions. The correction files were downloaded from (ftp://cddis.gsfc.nasa.gov/pub/gps/products/.)

3.2 Method

The data were processed using RTK Lib version 2.4.2 and G-Lab 5.4.0 in PPP mode. During processing, the elevation mask angle was set at 15° to limit the inclusion of low-elevation satellite signals. The ionospheric delay correction utilized the IONEX model, while the saastamoinen model was used for tropospheric delay correction. Additionally, all relevant correction files, including satellite orbit and clock files, were incorporated to correct for orbit and clock errors, respectively. These corrections were crucial in achieving accurate and precise positioning results.

In this study, the results provided by G-Lab were compared to the results generated by RTK Lib for the four stations. The analysis covered the data collected over the four months.

The results obtained from data processing were subjected to statistical analysis and the accuracy evaluation was carried out using Root Mean Square Error (RMSE).

4.0 Results and Discussions

The results of CORS data processed by G-Lab and RTK-Lib for August, October, November and December were processed in static PPP mode. It should be noted that the data were processed for 24 hours. From the results, we observed that the G-Lab software yielded a minimum Eastings of 6203493.024m and a maximum of 6326096.86m, with an average of 6264794.95m; minimum Northings of 375575.624m and a maximum of 833088.4296m with an average of 604332.025m, in addition, the height values, shows a minimum of 719131.8316m and a maximum of 1368114.98m with an average of 1043623.91m whereas the RTK Lib software resulted in a minimum Eastings of 6203495.583m and a maximum of 6326099.2m with an average of 6264797.4m. The Northings show a minimum of 375576.4679m and a maximum of 833087.5562m with an average of 604332.01m, In addition, the height values show a minimum of 719132.4747m and a maximum of 1368115.081m with an average of 1043623.78m. The above results signify the outstanding performance of RTK Lib software over G-Lab software because in all cases, RTK-Lab displays the least value of Eastings, Northings and heights with differences in magnitude of 2.45m, 0.015m and 0.91m in terms of Eastings, Northings and Height, respectively.

Furthermore, the Easting, Northing, and Height components of the four stations were used for the analysis. To assess the accuracy of the two software packages, we compared the root mean square errors (RMSE) of their respective outputs, as presented in Table 1. The RMSE is a widely used statistical metric for evaluating model performance across various fields, including meteorology, climate research studies, and air quality assessments.

Table 1: RMSE error for the stations for the four (4) months.

STATION	TYPE	GLAB (m)	RTKLIB (m)
ABUZ	X	1.8466	0.1663
	Y	0.8064	0.0223
	Z	0.2535	0.0654
BKFP	X	3.2300	0.1179
	Y	0.4049	0.0123
	Z	0.1683	0.0373
OSGF	X	0.5538	0.1671
	Y	0.3050	0.0219
	Z	0.3541	0.0268
ULAG	X	2.6250	0.1670
	Y	0.6459	0.0220
	Z	0.4248	0.0268

From the results (Table 1), we observed that the G-Lab software yielded a minimum RMSE Eastings of 0.5538m and a maximum of 3.2300m, with an average of 1.8919m; minimum RMSE Northings of 0.3050m and a maximum of 0.8064m with an average of 0.5557m, in addition, the height values, shows a minimum RMSE of 0.1683m and a maximum of 0.4248m with an average of 0.29655m whereas the RTK Lib software resulted in a minimum RMSE Eastings of 0.1179m and a maximum of 0.1671m with an average of 0.1425m. The Northings shows a minimum RMSE of 0.0123m and a maximum of 0.0223m with an average of 0.0173m, in addition, the height values, show a minimum RMSE of 0.0268m and a maximum of 0.0654m with an average of 0.0461m. The above results signify the outstanding performance of RTK Lib software over G-Lab software because in all cases, RTK-Lab display the least RMSE value of Eastings, Northings and heights with differences in terms of RMSE of 1.750m, 0.538m and 0.250 m for Eastings, Northings and Height respectively (see figure 2).

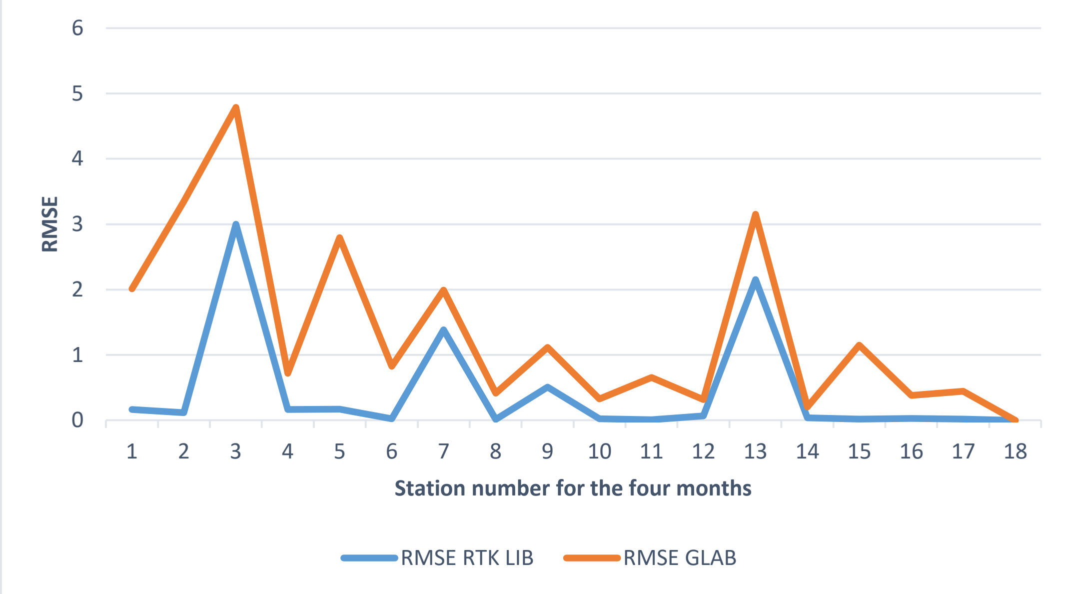

Figure 2: The RMSE values obtained from the two processing packages.

A lower RMSE value indicates higher model or software accuracy in GNSS data processing. However, it is essential to consider various factors that may influence the RMSE, such as data collected from low-quality receivers, data acquired under challenging environmental conditions, or inadequate pre-processing procedures. Figure 2 visually depicts the RMSE values obtained from the two processing packages, which shows the pattern of the signal structures between the RMSE of RTK LIB software and the RMSE of GLAB software. In all cases, the RTK LIB software shows the least RMSE when compared to the GLAB software.

5.0 Conclusion

This research compares the accuracy achieved by two GNSS processing software, namely G-lab and RTK Lib, when applied to processing Continuously Operating Reference Stations (CORS) data. The investigation involves processing four months of data collected from four CORS stations (ABUZ, BKFP, OSGF, and ULAG). The main focus is to assess which of the two software, G-lab or RTK Lib, demonstrates superior performance in processing GNSS data, as indicated by the results obtained from this comparative analysis.

The statistical analysis indicates that RTK Lib outperformed G-Lab in data processing, with a minimum RMSE Eastings of 0.1179m and a maximum of 0.1671m, with an average of 0.1425m. The Northings show a minimum RMSE of 0.0123m and a maximum of 0.0223m with an average of 0.0173m. In addition, the height values show a minimum RMSE of 0.0268m and a maximum of 0.0654m with an average of 0.0461m. Meanwhile, a minimum RMSE Eastings of 0.5538m and a maximum of 3.2300m, with an average of 1.8919m; minimum RMSE Northings of 0.3050m and a maximum of 0.8064m with an average of 0.5557m, in addition, the height values, shows a minimum RMSE of 0.1683m and a maximum of 0.4248m with an average of 0.29655m were obtained for G-Lab. The above results signify the outstanding performance of RTK Lib software over G-Lab software because in all cases, RTK-Lab display the least RMSE value of Eastings, Northings and heights with differences in terms of RMSE of 1.750m, 0.538m and 0.250m for Eastings, Northings and Height respectively. The results show that RTK-Lib software is more reliable for GNSS data processing. Future investigations should involve using one-year or longer data and considering more CORS stations to gain further insights. The implication of this study highlights the need for region-specific adaptations of open-source tools or the development of localized GNSS solutions to improve accuracy in national geospatial infrastructures.

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