Assessing the Accuracy of Online GNSS Processing Services and Commercial Software on Short Baselines

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Abstract

With the rapid establishment of free online processing services to provide users with reliable solutions, it is important to determine the reliability of using free online processing software for the Global Navigation Satellite System post-processing. The study aim at assessing the accuracy of two (2) free online processing software, AUSPOS, and CSRS-PPP and two (2) commercial software, compass post-processing, and GNSS solutions. Field observations were carried out on seven (7) control points using static GNSS observation techniques with an observation period of 1hr for three (3) consecutive days and conventional surveying using total station instruments to establish a closed traverse. The acquired data were post-processed using both online and commercial software. The co-ordinates generated from each software were then compared with the ones obtained using total station instruments to determine their relative discrepancies and accuracies. Root mean square error and T-test were used for the analysis of the result. The result obtained is (0.004m, 0.003m and 0.007m) for compass post-processing software and (0.015m, 0.012m and 0.016m) for GNSS solutions software and the online software had the Root Mean Square Error (RMSE) values of (0.025m, 0.023m and 0.027m) for AUSPOS and (0.034m, 0.037m and 0.041m) for CSRS-PPP both in X, Y, and Z direction i.e. UTM East, North and ellipsoidal height respectively. Analysis at a 5% level of significance shows no significant difference between the two methods. Online GNSS processing services are easy to use, do not require the knowledge of GNSS data processing and can be adopted for engineering and geodetic applications.

Keywords: *Online processing services, GNSS, AUSPOS, CSRS-PPP, Commercial Software*

1. Introduction

Global Navigation Satellite Systems (GNSS), is a generic term for all the satellite-based global navigation systems at the end of the twentieth century, which started a new and exciting era in positioning, navigation, and timing (Choy, 2009; Isioye *et al.,* 2018). Accurate estimates of position, velocity, and time have become available to all virtually instantaneously, continuously, inexpensively, and effortlessly (Misra and Enge, 2006).

At present, GNSS including the GPS, GLONASS, Galileo, and BeiDou, establish the foundation for contemporary positioning applications such as agriculture, mapping, public safety, military, surveying purposes and Geographical Information System (GIS) (NGS, 2017; Hoffmann-Wellenhoff *et al.*, 2008; Tata, 2017). Some of these applications necessitate a precise geodetic observation that cannot be accomplished with raw measurements. Therefore, the error sources from the satellite system, the receiver system, and the signal path must be eliminated. This can be achieved through an effective correction process which is divided into real-time based and post-processing based (Tariq *et al.,* 2017). The real-time based techniques such as differential GPS (DGPS), Real-Time Kinematic (RTK) and the wide-area augmentation system, use satellite receiver intersystem communication to generate the position of a point. This type of differential positioning is significant in the applications that necessitate immediate results. The post-processing procedures apply the corrections after the GPS data has been collected (Tariq *et al.,* 2017).

The diverse accuracies of GNSS positioning necessitate its study to evaluate its accuracy for different applications. Some applications require meter level positioning, while others require centimetre level. However, to ensure accurate positioning, two GNSS receivers need to be employed and post-processing of the data with scientific or commercial software while one receiver is needed with online processing services due to the vulnerability of real-time kinematic techniques to poor satellite visibility, multipath and unreliable data link from the reference station. Due to the ease of use and no requirement of experience in GNSS post-processing, online processing services have now become an alternative to the scientific and commercial software in GNSS data processing.

A notable study in GNSS post-processing was done by Tariq *et al.,* (2017). The authors evaluated the accuracy of three online processing services (OPUS, AUSPOS, CSRS-PPP) and one offline software (LGO v8.3). Two GNSS observation techniques (static and rapid-static) were used to obtain necessary data and the duration of observation for each point was divided into five periods (2hr, 4hr, 6hr, 8hr, and 10hr). The result obtained through the LGO software used in the Rapid Static (RS) technique shows a root mean square error (RMSE) of 0.011m which made it to be the closest software in terms of convergence with field measurements. AUSPOS gave better results among the online processing services with RMSE values of 0.041-0.018m, while OPUS results range between 0.043-0.260m and CSRS-PPP results range between 0.046-0.250m respectively. It was concluded that there is no association between processing results at the same point for different free online processing services. The authors also concluded that AUSPOS accuracy is regular with the observation period when the observation time is longer and users can expect reliable results from online services during the observation period of 10hr at a millimeter level.

A study carried out by Adam (2017) focused on the use of online and offline processing tools to improve the precision of a GPS passive station. In this study, GPS raw data of roughly 121hr was broken into 36 sub-files covering five days of observation, each containing a full of 24hr, 12hr, and 6hr of data at 1second epoch was collected and processing was done using CSRS-PPP, OPUS, AUSPOS along with offline-PPP software. The results revealed that the horizontal and vertical RMSE decreases with an increase of observation time. The RMSE for the horizontal and vertical components was found to be less than 6mm and 10mm respectively for all sessions and processing services.

El-Mowafy (2013) made a comparison between two of the online post-processing services (AUSPOS and CSRS-PPP) and used four datasets of 1hr, 1.5hr, 2hr, and 3hr of length in three different locations. It was concluded that AUSPOS has an accuracy of a few millimeters to a couple of centimeters in the static mode for the horizontal coordinates and centimeters in vertical while CSRS-PPP also gave the accuracy of few millimeters to centimeters for the planimetric positions, but the vertical error was up to a decimeter.

In a study conducted by Abd-Elazeem *et al*. (2011), CSRS-PPP was used to process and estimate differences in single-frequency GPS observations in static mode at three locations with observation periods of 1hr, 1.5hr, and 2hr at different baselines of 1.6km, 7km, and 10km respectively. The study shows that single-frequency PPP has an accuracy of a few decimeters for the horizontal coordinates.

From all related work, it can be noticed that no study considered the comparison of the online processing services' accuracy with the commercial software. Except for one, all the studies used one commercial software and did not test whether there is a significant difference between the results obtained from the online processing services and commercial software. Two commercial software packages will be used in this study and the test will be conducted to ascertain whether there is a significant difference between the results of the online processing services and commercial software. In this study, the aim is to investigate the accuracy of the free online processing services and commercial software on short baselines using three days' worth of data with the observation session of 1hr to determine the reliability of the online services for a shorter period so that its full potential can then be explored by different professionals. To evaluate the accuracy, two of the post-processing online services (AUSPOS and CSRS-PPP) and two commercial software (compass post-processing and GNSS solutions) have been used to estimate the coordinates of low order temporary control stations which are suitable for engineering work requiring cm-dm level of accuracy. In practice, the estimation of coordinates of temporary control points is mostly performed using short data sets (only a few hours of measurements) for logistic and economic reasons compared to higher-order control stations which require long periods of observations.

1.1. Online Post-Processing Services

To position with GPS, it is very important to use at least two GNSS receivers to achieve centimeter-level accuracy. It is also important to post-process the acquired data using GNSS data processing software whether scientific or commercial to obtain accurate results. Nowadays, processing of GPS data for both positioning (static and kinematic) techniques, is possible via free online web-based processing engines. GNSS online processing services are now widely used as an alternative to the traditional processing method. The use of these processing services has become widely popular because of their ease of use, is free of charge (or requiring a low-cost fee) and no requirement of a license and knowledge of a GPS processing software (Alkan, 2016). The users of these services need to convert the acquired GNSS data to Receiver Independent EXchange (RINEX) format (El-Mowafy, 2013; Oluyori, *et al.,* 2019) and send through email or upload it to a particular website. After uploading the data, the coordinates can easily be obtained a few minutes later via the user's registered email. It is nowadays possible of data processing for both positioning modes, static and kinematic, via these free online web-based processing engines (Alkan, 2016). Figure 1 shows the online-based GNSS processing method.

Figure 1: Online Based GNSS Processing Method (Alkan, 2016)

Several agencies (NASA JPL, National Geodetic Survey Canada, GMV Innovating Solutions, Geoscience Australia, SOPAC, National Geodetic Survey, and Trimble) have established web services where dual or single frequency GPS data processing is possible and some of these services (e.g. AUSPOS, SCOUT, and OPUS) calculate the coordinates with a relative solution or double differenced phase measurements approach while others (e.g. CSRS-PPP, MagicGNSS, and APPS) use PPP technique based on the processing from a single GPS receiver employing precise orbit and clock corrections. Most of the online services use International GNSS Services (IGS) orbit products upon availability (Adam, 2017). AUSPOS which is seen as more user friendly and CSRS-PPP which is popular among the PPP technique based online processing services are selected for this study.

1.1.1. AUSPOS

AUSPOS is a free online GNSS processing service developed by Geoscience Australia and it uses the Bernese GNSS Software for processing baselines and takes advantage of both the IGS Stations Network and the IGS product range and compatible data acquired anywhere on Earth. Access is through a simple web interface, the antenna height and type are entered along with an email address for the returned report set. AUSPOS service is accessible via the Geo-science Australia website at http://www.ga.gov.au.

1.1.2. CSRS-PPP

CSRS-PPP provides an online service for GNSS data post-processing allowing users to compute high precision positions from their raw observed data. CSRS estimates are computed from carrier phase or code pseudo-range observations of both single and dual-frequency receivers. Users can submit observed data in RINEX format from single or dual-frequency receivers operating in static or kinematic mode over the internet for onward processing. This service is available through the GSD website at http://www.geod.nrcan.gc.ca.

1.2. Commercial GNSS Processing Software

1.2.1. Compass Post-Processing Software

The Compass Post Processing Software is the GNSS processing software from CHC. This software is utilized for processing the GNSS data as a post-processing differential solution between a base station (reference) and an unknown station (rover station) and can be considered as a commercial software package. Compass post-processing software can download the observation data (raw data) from the GNSS receiver and export it into the RINEX file and other formats.

1.2.2. GNSS Solutions (v 3.8)

GNSS Solutions is a comprehensive office software with all of the tools required to successfully process GPS, GLONASS, and Satellite Based Augmentation System (SBAS) survey data. It gives optimal results from any combination of static, rapid static, or kinematic data. The software supports a wide range of surveying applications whether conducted in real-time or static mode. The GNSS solutions software can import and export GNSS data in RINEX and other formats.

1.3. Study Area

The study area selected for this study is the Federal University of Technology, Akure, Ondo State in the South-Western part of Nigeria. The geographic location lies approximately between latitude 07º 18' 07.80" N to 07º 17' 46.92" N and Longitude 05º 08' 24.06" E to 05º 08' 45.42" E. Figure 2 below shows the study area location.

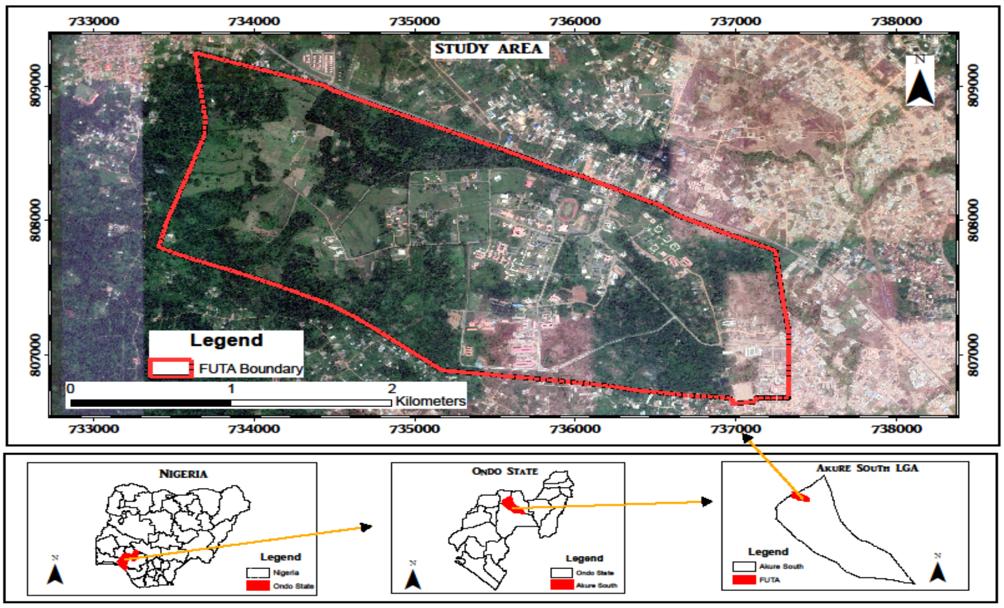

Figure 2: Study Area Map

2. Materials and Method

The data that were used for this study was from the field survey, which involved data acquisition using an electronic total station (STONEX R2 PLUS) and differential GPS (CHC X900).

2.1. Data Acquisition

Data acquisition is the process of capturing, collecting, and gathering data or information from the field or any other sources before it can be transformed into reality for usage. For this study, total station instrument and GPS was used to acquire raw data on the field.

2.1.1. Total Station Traversing

In this study, the total station was used to perform a closed connected traverse on seven (7) selected control points starting from a known point and finishing on a known point. The three-dimensional coordinates (E, N, h) of these points in Universal Transverse Mercator Projection (UTM) were obtained. This is to enable the evaluation of the accuracy of the processing results of the GNSS data obtained from the online GNSS post-processing service and commercial GNSS processing software. Figure (3) reveals the field survey of the closed-loop traverse.

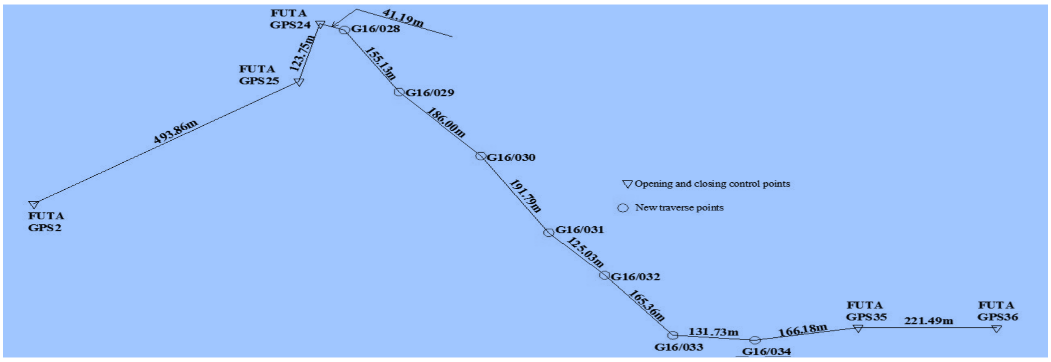

Figure 3. Field survey of the closed-loop traverse.

2.1.2. GPS Observations

CHC X900 differential GNSS receiver was used to acquire the 3D coordinates of the seven (7) selected control points within the study area. The GPS base receiver was set up on the FUTA GPS02 control point centered and levelled to serve as the reference station. The GPS rover was set up serially over the seven (7) selected control points in a static mode with observed time (1hr) for each point to track enough satellites to enhance the quality of data streaming for more reliable accuracy.

2.2. Data Processing

The processing strategy adopted in this study includes; downloading of acquired data from the total station instrument, conversion of acquired GPS data (base and rover receivers) to RINEX using

HcRinex software before sending it to the online processing services (AUSPOS and CSRS-PPP) for processing to obtain an accurate position for which the results were sent to the email address provided during data uploading. The other processing involved the usage of commercial software (Compass Post-Processing and GNSS Solutions Software) to obtain the coordinates of the observed points.

3. Results and Discussion

3.1. Presentation of Results

The results obtained from this study are the coordinates of seven (7) selected control points determined (using total station) which were observed through GNSS observation and were post-processed using Online GNSS processing service and commercial software. The coordinates obtained from AUSPOS which was based on Geodetic Reference System (GRS80) ellipsoid and International Terrestrial Reference Frame (ITRF 2014), and that of CSRS-PPP which was based on North American Datum (NAD83) were both converted to World Geodetic System (WGS84) using CoordTransform software and the UTM coordinates (E, N, h) was obtained. The differences between coordinates obtained with a total station and the ones obtained by GNSS observation post-processing method using Online GNSS processing service (AUSPOS and CSRS-PPP) and commercial software (Compass Post-Processing and GNSS Solution) have been calculated as well as the Root Mean Square Error (RMSE) of post-processed defined coordinates. Tables 1 to 4 show the differences between coordinates obtained with the total station and the GNSS processing software.

Table 1: Total Station and Compass Post-Processing Software differences

Point	E (m)	N (m)	h (m)
G16/028	-0.003	0.002	-0.005
G16/029	0.004	-0.004	0.001
G16/030	0.006	0.003	-0.002
G16/031	-0.004	-0.002	0.012
G16/032	0.006	0.004	-0.004
G16/033	-0.001	0.003	0.007
G16/034	0.003	0.005	0.010

Table 2: Total Station and GNSS Solutions Software differences

Point	E (m)	N (m)	h (m)
G16/028	0.000	0.001	-0.008
G16/029	0.026	0.025	-0.011
G16/030	0.010	0.009	0.035
G16/031	-0.021	-0.004	-0.007
G16/032	0.014	-0.002	-0.014
G16/033	0.000	-0.013	-0.013
G16/034	-0.008	0.006	0.002

Table 3: Total Station and AUSPOS differences

Point	E (m)	N (m)	h (m)
G16/028	-0.025	0.017	-0.033
G16/029	0.012	-0.019	0.026
G16/030	-0.018	0.020	0.021
G16/031	0.021	-0.030	0.020
G16/032	-0.026	0.022	-0.017
G16/033	0.031	0.028	-0.035
G16/034	0.034	0.024	0.028

Table 4: Total Station and CSRS-PPP differences

Point	E (m)	N (m)	h (m)
G16/028	-0.025	-0.040	0.028
G16/029	-0.033	0.049	0.039
G16/030	-0.021	0.026	-0.034
G16/031	-0.043	-0.032	-0.071
G16/032	0.027	0.031	0.035
G16/033	0.037	-0.036	-0.031
G16/034	0.042	0.038	-0.032

3.1.1. Root Mean Square Error (RMSE)

The RMSE, is a frequently used measure of the difference between values observed from different sets of measurements. These individual differences are also called residuals, and the RMSE serves to combine them into a sole measure of extrapolative power. Therefore, the RMSE of the processed coordinates (obtained by GNSS software) with respect to the observed coordinates (obtained with total station instrument) is defined as the square root of the mean squared error. For this study, n (i = 1 - 7) control points were observed with a total station and dual-frequency GPS. The GPS data was observed three times and was post-processed with the GNSS software to obtain the 3D coordinates of the control points. Thus, the 3D coordinate of each point was averaged to obtain the most probable value of the points. Then if XObs, YObs, and ZObs are the observed/standard coordinates of the control points and XProc, YProc and ZProc are processed coordinates of the control points, estimates of the root mean square spatial residual along the X, Y, and Z directions i.e., Eastings, Northings, and Heights respectively are given by the following formulae:

The X-direction: $$rmseX = \sqrt{\frac{\sum_{i=1}^{n}(X_{Obs,i} - X_{Proc,i})^2}{n}} \quad [1]$$

The Y-direction: $$rmseY = \sqrt{\frac{\sum_{i=1}^{n}(Y_{Obs,i} - Y_{Proc,i})^2}{n}} \quad [2]$$

The Z-direction: $$rmseZ = \sqrt{\frac{\sum_{i=1}^{n}(Z_{Obs,i} - Z_{Proc,i})^2}{n}} \quad [3]$$

Where; *n* is the total number of points, X_{Obs}, Y_{Obs}, and Z_{Obs}, are observed coordinates/standard coordinates of the point ***i*** and X_{Proc}, Y_{Proc}, and Z_{Proc}, are processed coordinates of the point ***i***.

The smaller the value of the RMSE estimates the better the accuracy attainable with the 3D coordinates obtained from the GNSS processing software. The summary of the RMSEs of the GNSS processing software is presented below:

Table 5: Accuracy assessment (Summary of RMSEs of the GNSS processing software)

GNSS Processing Software	rmse X (m)	rmse Y (m)	rmse Z (m)
Compass Post-Processing Software (Commercial)	0.004	0.003	0.007
GNSS Solution Software (Commercial)	0.015	0.012	0.016
AUSPOS Processing Service (Online)	0.025	0.023	0.027
CSRS-PPP Processing Service (Online)	0.034	0.037	0.041

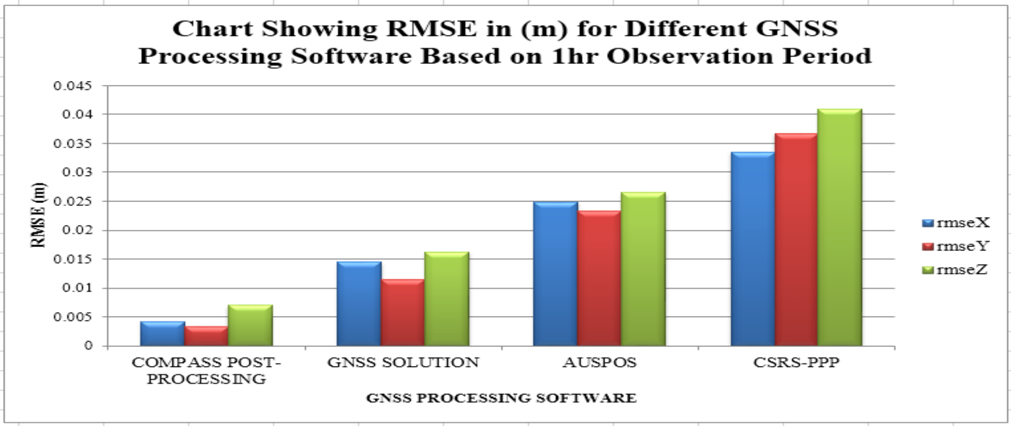

Figure 4: RMSE in (m) for different GNSS Software based on 1hr observation period

3.2. Discussion of Results

Using insight into Table 6 above, the following points were noted:

a) The coordinates of points obtained from post-processing with the two commercial GNSS processing software (Compass Post-Processing Software and GNSS Solution Software) were of better accuracy than co-ordinates obtained from post-processing with the two online processing software (AUSPOS and CSRS-PPP).

b) In the X, Y, and Z direction, the best accuracy was obtained from commercial software used for the post-processing with compass post-processing software with the calculated root mean square errors of 0.004m, 0.003m and 0.007m in X, Y and Z direction respectively.

c) According to the obtained results, AUSPOS online processing software gives better results with calculated root mean square errors of 0.025m, 0.023m, and 0.027m in the X, Y, and Z direction than the CSRS-PPP which is a PPP software.

d) According to the obtained results, the minimum error was provided by the commercial software when compass post-processing software was used.

e) The maximum error was provided by the online software when CSRS-PPP was used with calculated root mean square errors of 0.034m, 0.037m, and 0.041m in the X, Y, and Z direction respectively.

f) Also, the obtained results depict that the accuracy of the GNSS processing software was influenced by the observation period (1hr) used in acquiring the data which is an important factor when using online GNSS processing software.

3.3. Hypothesis Testing

The hypothesis testing was performed by comparing coordinates generated from compass post-processing software (commercial software) with co-ordinates generated from AUSPOS processing services (online software) and also that of co-ordinates generated from compass post-processing software (commercial software) with co-ordinates generated from CSRS-PPP (online software) to further examine their level of significance based on the equality of mean (co-ordinates) vectors with the population variance unknown using T-distribution. This is a two-tail test where the Null hypothesis is rejected if the computed statistic is more than the upper limit and less than the lower limit of the table statistic. The t-test hypothesis was performed using Microsoft Excel 2010 and is stated below:

Null Hypothesis: $H_0 : X_1 = X_2$ [4a]

Alternative Hypothesis: $H_i : X_1 \neq X_2$ [4b]

To test the hypothesis that there is no significant difference between the co-ordinates generated from commercial software and online software on short baseline observation processing

Decision Rule: H_0 may be rejected at 0.05 significant level if $t > t_{1-\alpha/2}$, $t < t_{\alpha/2} = t_{0.975} > t > t_{0.025} = 2.447 > t > -2.447$

Decision: H_0 was accepted; since the computed t for compass post-processing software versus AUSPOS are 0.179, 0.899, -0.118 and that of compass post-processing software versus CSRS-PPP are -0.371, 0.151, -0.428, which was greater than the t from the table (-2.447).

It is worth concluding that, there is no significant difference between the co-ordinates generated from commercial software and online software on short baseline observation processing.

4. Conclusion

The accuracy of GNSS processing software using four (4) different types of software which consists of two (2) online software and two (2) commercial software was investigated in this study. In this study, a standard total station instrument was used as the reference for the discrepancy comparison. The GNSS observation method used was compared against the total station by considering co-ordinate measurements of the same points in both methods. The observations were carried out for three (3) consecutive days on each of the control points and were later post-processed using two commercial software and two online software. The used software includes both relative and precise point positioning (PPP) technique. The coordinates obtained from the post-processing were then averaged to obtain the most probable value of each point in X, Y, and Z directions, i.e. Easting, Northing, and Ellipsoidal height. A total of seven (7) control points were used for the investigation. The accuracy of each software was assessed using the Root Mean Square Error approach for data analysis and hypothesis testing was performed on the two software statistically using T-distribution which shows that there is no significant difference between the two software for short baseline. GNSS online processing is easy to use and does not require a license and knowledge of GPS processing techniques compared to the commercial software that requires GNSS knowledge and experience in the data processing, and in addition to the cost of the software licensing. Although the results of data processing through online processing software depend on some factors, users of these services can expect better results when the time of observation is longer with a dual-frequency GNSS receiver which will allow ambiguity resolution thereby increasing the accuracy.

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