Comparative Analysis of Different Online GNSS Processing Services

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Abstract

Nowadays, online GNSS processing services for GPS data processing developed by several organizations; which are user friendly, unlimited and most of them are free; easy to use and does not require a license and knowledge of GPS processing software compare to the commercial software that require knowledge of the GNSS and experience in the processing, in addition to the cost of the software licensing for post processing and analysing of GPS data have become widely used. New developments over algorithms of GPS point positioning and accuracy enhancement of the products provided by organizations (IGS etc.) increase the number and the quality of these services. The aim of this study is to perform comparative analysis of different online GNSS processing services used around the world (namely AUSPOS, CSRS-PPP, MagicGNSS/PPP, APPS and GAPS). These services employ relative and precise point positioning (PPP) solution methods. In this study, field observations were carried out on seven (7) selected control points using static GNSS observation techniques with observation session of 1hour and the control points were also observed by using conventional surveying where total station instrument was used to established a closed traverse. The 3D co-ordinates of the control points were estimated using the online processing services and the co-ordinate differences between these services and total station co-ordinates were computed. The accuracy of each online processing service was determined using the Root Mean Square Error (RMSE) approach. From the evaluations, it was seen that the results for each online processing services in the X, Y, and Z directions were (2.49cm, 2.33cm, and 2.41cm) for AUSPOS, (3.35cm, 3.67cm and 3.19cm) for CSRS-PPP, (4.20cm, 3.60cm, and 3.43cm) for MagicGNSS/PPP, (6.91cm, 7.71cm, and 10.61cm) for APPS and (6.81cm, 7.77cm, and 9.09cm) for GAPS. According to the results, AUSPOS which employed relative positioning service has more reliable results than other services which employed precise point positioning service. CSRS-PPP has the more reliable results among other PPP services. The results show that the position accuracies attained by associated online services deliver high accurate solutions that may be used in many engineering applications and geodetic analysis.

1.0 INTRODUCTION

The meaning of GNSS is the technical interoperability and compatibility between various satellite navigation systems such as modernized GPS, Galileo, reconstructed GLONASS to be used by civilian users without considering the nationalities of each system in order to promote the safety and convenience of life (GALILEO, 2003; Feng, 2003). GPS is a popular utility that provides both military and civilian users with positioning, navigation, and timing services regardless the weather conditions. The free availability of GPS signals' globally and its accuracy for positioning and timing, in addition to the low cost of receiver chipsets, made the GPS excellent solution for a broad range of civilian applications. Over recent years, the GPS has dramatically increased productivity and resulted in more accurate and reliable data which led to being used dependably by surveying community. To allow rapid and accurate data collection, land surveyors mount GPS rover on vehicles or carry it in a backpack. The rover can communicate wirelessly with reference receivers in order to deliver continuous, real-time, centimetre-level accuracy, and unprecedented productivity (Gps.Gov, 2016). Conventionally, to produce centimetre-level positioning accuracy, at least two geodetic-quality survey receivers required to simultaneously tracking common satellites.

Not too long ago, to position with GPS, it was essential to employ at least two receivers. It was also necessary to post-process the collected data using the GNSS data processing software whether scientific or commercial to obtain accurate results. Nevertheless, the usage of such software is also quite difficult because they require knowledge of the GNSS and experience in the processing, in addition to the cost of the software licensing (Adam, 2017).

Online services present two types of solutions, which are relative solution approach and precise point positioning (PPP) solution approach. The services that are based on relative solution approach use national Continuously Operating Reference Stations (CORS) or IGS stations as reference control points. The services that are based on PPP solution approach use GPS-only or GPS+GLONASS products (such as orbit & clock corrections). Both of the solution types have been used widely and effectively for monitoring the deformations such as on landslides, structural behaviors and mining, marine applications (i.e. hydrographic surveys), geographic information systems (GIS), engineering surveys, mapping applications, as-built surveys etc. In recent years, coordinates obtained from these services have been used for geodetic analyses that require high accuracy as well (Ocalan et al., 2013).

The GNSS positioning and Total Station positioning have diverse accuracies. Thus, studying each positioning technique is necessary to evaluate its accuracy for different applications. In relative positioning, at least one or more reference stations are required to determine the unknown positions, while the Precise Point Positioning (PPP) just needs one receiver without base station. Some applications require meter level or centimetre level of accuracy and this depends on the required accuracy. The main objective of the study is exploring this problem in terms of the coordinate's disparity for each point. Therefore this study aims to find the quantity of the coordinate variation, the reliability of each available procedure, and to recommend the highest reliability available service. This approach is basically divided into two sections. First, data acquisition (traversing and static observation), second is data processing (static-observation processing) and result generation. In this study, five different online GNSS processing services have been presented with their general characteristics and web addresses, and static-observation processing is done using these services (AUSPOS, CSRS-PPP, MagicGNSS/PPP, APPS, and GAPS) to generate the 3D spatial co-ordinates.

2.0 METHODOLOGY

The methodology for this work is divided into three main parts. Firstly, horizontal position for seven (7) control stations was established using static GNSS positioning techniques based on the online GNSS processing services. For this purpose, dual frequency GNSS receiver (CHC X900) was used and the station observation time was one (1) hour. Secondly, Total Station instrument type (Stonex R2 plus) is used to observed the control stations and closed traverse was established. Finally, accuracy assessment of the results obtained from the online processing software with total station traverse observation is performed.

3.0 ONLINE GNSS PROCESSING SOFTWARE

In the recent years a number of organizations have sophisticated online Global Navigation Satellite System (GNSS) for the processing services, which provide the users GNSS processing data to the use free of upload and with unlimited access. These processing services supply solutions for a user submitted Receiver Independent Exchange Format (RINEX) file depend on differential technique with reference stations or precise point positioning technique using IGS Orbit Products (Ghoddousi-Fard, R. and Dare, P. 2006).

Online services present two types of solutions, which are relative solution method and precise point positioning (PPP) solution method. The services that are based on relative solution approach use national Continuously Operating Reference Stations (CORS) or IGS stations as reference control points. The services that are based on PPP solution approach use GPS-only or GPS+GLONASS products (such as orbit & clock corrections). The general characteristics of the services and their web addresses are discussed below;

3.1 Services using Relative Solution Method

Traditionally, most of the professional GPS users have used relative positioning technique to provide high accuracy. However, this technique has some disadvantages related to PPP technique, such that minimum two or more GPS receivers should be used and the true coordinates of the reference stations should be known. Addition to this, increase of the distance between reference station and rover station has reduced the position accuracy (Abd-Elazeem et al., 2011).

The strategy of setting up CORS networks for processing GPS data in relative positioning technique has provided important advantages. These networks, which are set up and have operations in global, regional, national and local levels, eliminate the requirement of constructing reference stations in faraway locations from GPS surveying areas. Nowadays, by the help of both reference stations that collect continuously 7 day x 24 hour data and established networks, producing new control points by relative positioning technique is used frequently. The coordinates of new points have been estimated easily by using continuous and seamless daily RINEX data belonging to these stations for many surveying applications (Ocalan, T. et al., 2013). In addition to these, online GNSS processing services that are using relative solution method estimates the position of point anywhere on the earth through the double-difference technique by making use of IGS network data or CORS network data.

There are three (3) online GNSS processing services that employed relative solution approach and they are Online Positioning User Service (OPUS), Australian Online GPS Processing Service (AUSPOS) and Scripps Co-ordinate Update Tool (SCOUT). For this study, AUSPOS is being used and is discussed below;

3.1.1 Australian Online GPS Processing Service (AUSPOS)

AUSPOS is a free online GNSS processing service from Geoscience Australia. Access is through a simple web interface, the antenna height and type are entered along with a email address for the returned report set. GPS data file submission is through FTP or directly from the web interface.

AUSPOS uses the Bernese GNSS Software for processing baselines and takes advantage of both the IGS Stations Network and the IGS product range and works with data collected anywhere on Earth. Users submit their dual frequency geodetic quality GPS RINEX data observed in 'static' mode to the GPS data processing system. An AUSPOS report will be emailed to the email address provided in the course of processing which contains Geocentric Datum of Australia 1994 (GDA94) and International Terrestrial Reference Frame (ITRF) co-ordinates of points.

RINEX files need to be at least 1-hour in length, 6-hour files are recommended. Compact RINEX files are also accepted. Files may be compressed with UNIX, Hatanaka, ZIP, gzip or bzip compression. AUSPOS service is accessible via the Geo-science Australia website at: http://www.ga.gov.au

3.2 Services using Precise Point Positioning (PPP) Solution Method

Precise Point Positioning (PPP) stands out as an optimal approach for providing centimeter-level error positioning using current and coming GNSS constellations. The PPP processes measurements from a single user receiver, using detailed physical models and corrections, and precise GNSS orbit and clock products computed beforehand. PPP differs from other precise-positioning methods like Real Time Kinematics (RTK) in that no reference stations are needed in the vicinity of the user.

PPP uses un-differenced ionospheric-free both carrier-phase (Φ) and code pseudorange (P) observations collected by dual-frequency receiver for data processing. This technique provides precise positioning by using precise ephemeris and clock products provided by IGS and other organizations and by considering other corrections such as satellite effects (satellite antenna offsets and phase wind-up), site displacement effect (solid earth tides, polar tides, ocean loading, earth rotation parameters) and compatibility considerations (products formats, reference frames, receiver antenna phase center offsets, modeling/observation conventions) (Zumberge et al., 1997; Kouba and Héroux, 2001; Kouba, 2009; Abd-Elazeem et al., 2011). As stated in both Zumberge at al.(1997) and Kouba and Heroux (2001), the ionospheric-free combinations of dual-frequency GPS pseudorange (P) and carrierphase observations (Φ) are related to the user position, clock, troposphere and ambiguity parameters.

There are several online services and software products implementing a PPP processing strategy which have been developed recently by government agencies, universities, industries and individuals. They are discussed below;

3.2.1 Canadian Spatial Reference System- Precise Point Positioning (CSRS-PPP)

CSRS-PPP is an online application for GNSS data post-processing allowing users to compute higher accuracy positions from their raw observation data. It makes use of the precise GNSS satellite orbit ephemerides to produce corrected coordinates of a constant “absolute” accuracy no matter where you are on the globe, regardless of proximity to known base stations. . CSRS estimations are computed from carrier phase or code pseudo-range observations of both single and dual frequency receivers.

Users can submit RINEX observation data from single or dual-frequency receivers operating in static or kinematic mode over the internet and recover enhanced positions in the Canadian Spatial Reference System (CSRS) and International Terrestrial Reference Frame (ITRF).

This service has actively processed GLONASS data from 4 October 2011 and accepted user provided ocean tidal loading (OTL) correction files from 14 February 2012. This service is available via the GSD website at: http://www.geod.nrcan.gc.ca

3.2.2 MagicGNSS Precise Point Positioning (MagicGNSS/PPP)

MagicPPP is a worldwide positioning service that allows GNSS users to determine their position or trajectory with centimeter-level accuracy. magicPPP implements new generation Precise Point Positioning (PPP) algorithms developed by GMV as a result of more than 30 year’s experience in GNSS based precise orbit determination, time synchronization and positioning.

Unlike other traditional techniques for high precision positioning such as RTK, the technique implemented in magicPPP does not require data from Continuous Operating Reference Stations (CORS) in the proximity of the user. It is an ideal solution for precise trajecto-graphy over long distances and/or areas out of CORS coverage. magicGNSS’ PPP Correction Service relies on multi-GNSS precise orbits and clocks computed in a real-time basis by magicGNSS’ POD engine, processing code-phase and carrier-phase GNSS observations coming from a worldwide station network. These precise orbits and clocks are used to compute corrections to the GNSS broadcast ephemeris, which are provided to the user over the Internet allowing high accuracy positioning performances regardless the user location. This service is accessible via http://www.magicgnss.gmv.com/ppp

3.2.3 Automatic Precise Positioning Service (APPS)

APPS accepts GPS measurement files, and applies the most advanced GPS positioning technology from NASA's Jet Propulsion Laboratory to estimate the position of your GPS receivers, whether they are static, in motion, on the ground, or in the air. APPS employ:

- Real-time GPS orbit and clock products from JPL's GDGPS System
- JPL's daily and weekly precise GPS orbit and clock products
- JPL's GIPSY-OASIS software for processing the GPS measurements

APPS continue to provide JPL's venerable AutoGIPSY (AG) service - for free, for static post-processing (e.g. measurement latency of a week or more), but also offers new and unique services. APPS uses final, rapid, ultra rapid precise GPS orbit and clock products of JPL. The users may also use Site Displacement Effects (Solid Earth Tides and Ocean Tidal Loading) in processing if they prefer. APPS send the solution through email. APPS supports input in RINEX 2, RINEX 2.11 input files, GIPSY TDP files. The site is accessible through http://apps.gdgps.net/

3.2.4 GPS Analysis and Positioning Software (GAPS)

The GNSS Analysis and Positioning Software (GAPS) was initially developed in 2007 at the University of New Brunswick in order to provide users with a free online PPP tool capable of estimating positions and other parameters of interest. Although mainly used for positioning, GAPS was designed and built as a veritable "Swiss Army Knife" for GNSS data processing, allowing the user to estimate ionospheric and neutral atmospheric delays, receiver clock and inter-system biases, and code multipath.

GAPS provide users with accurate satellite positioning using a single GNSS receiver both in static and kinematic mode. Through the use of precise orbit and clock products provided by sources such as the International GNSS Service (IGS) and Natural Resources Canada (NRCan), it is possible to achieve centimetre-level positioning in static mode and decimetre-level positioning in kinematic mode given a sufficient convergence period. The site is accessible via http://gaps.gge.unb.ca/

4.0 STUDY AREA

The study area for this work lies between latitude 07^{o} 18’ 07.80”N, 07^{o} 17’ 46.92”N and Longitude 05^{o} 08’ 24.06”E, 05^{o} 08’ 45.42”E in Federal University of Technology, Akure in Akure South Local Government Area, Ondo State, Nigeria with seven unknown control points which are selected on the basis of visibility between the previous and subsequent points, and avoidance of any effective obstructions. Figure 1 below shows the study area location.

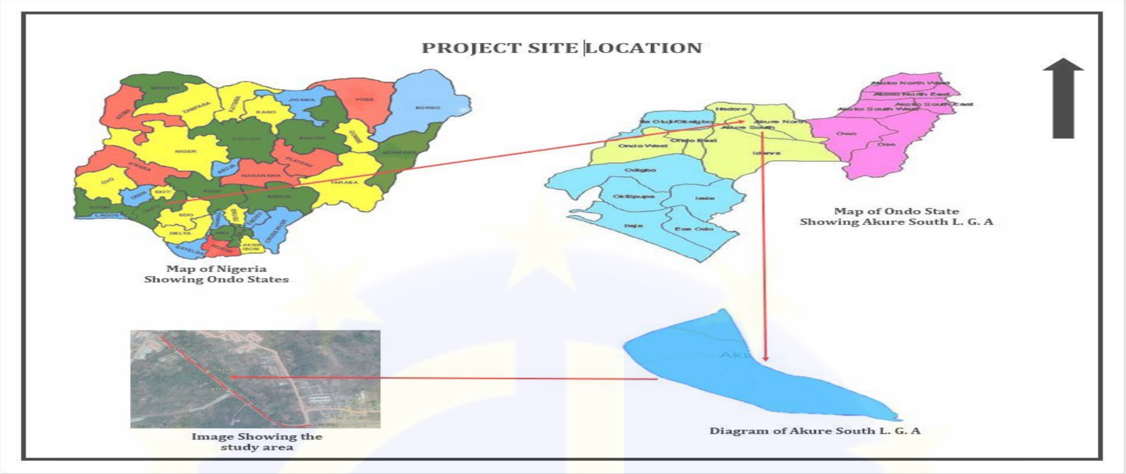

Figure 1: *Study Area*

5.0 FIELD OBSERVATION

5.1 Static Observations

In this study, dual frequency CHC X900 GNSS receiver was used to determine the horizontal position of seven (7) selected unknown control stations. The GPS base receiver was set up on a reference station, temporary adjustment was carried out and all precautions were taken. The Rover was set one after the other over the seven (7) unknown selected control points. The GPS rover receiver was allowed to track satellites for a minimum of one hour (1hr) on each point in order to have a good accuracy. Figure 2 below shows the static GNSS observation with CHC X900 differential GPS.

Figure 2: *Static GNSS Observation. Base (fixed device on left), Rover (moved device on right)*

5.2 Traversing

In this study, a closed connected traverse was also performed on the seven (7) selected control stations starting from known point and end on a known point using Total Station (STONEX R2 PLUS) where the three-dimensional coordinates (X, Y, Z) of these points were obtained. This is to enable the evaluation of the accuracy of the processing results of the GNSS data obtained from the online GNSS processing services.

6.0 DATA PROCESSING

After the field observations data are achieved, the raw data was downloaded to personal Computer (PC) from base and rover receivers, the base receiver and rover receiver observations data was converted to RINEX format using HcRinex software, and compressed with Hatanaka software. The collected raw data from the static observations was processed using five (5) of the online GNSS processing services AUSPOS, CSRS-PPP, MagicGNSS/PPP, APPS and GAPS.

7.0 RESULTS AND ANALYSIS

The results obtained from this study are the coordinates of seven (7) selected control point determined (using total station) which were observed through GNSS observation and post-processed using five (5) Online GNSS processing services. The differences between coordinates obtained with Total station and the ones obtained by GNSS observation post-processing method using Online GNSS processing services (AUSPOS, CSRS-PPP, MagicGNSS/PPP, APPS and GAPS) have been calculated. The statistical validity of results derived can be assessed by considering the Root Mean Square Error (RMSE).

The Root Mean Square Error (RMSE), also called the Root Mean Square Deviation, is a frequently used measure of the difference between values observed from different sets of measurement. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power. Therefore the RMSE of the processed coordinates (obtained by GNSS software's) with respect to the observed coordinates (obtained with Total Station instrument) is defined as the square root of the mean squared error.

In this study, n (i = 1 - 7) control points were observed with total station and dual frequency GPS. Thus, 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: $$rmsX = \sqrt{\frac{\sum_{i=1}^{n}(X_{Obs,i} - X_{Proc,i})^2}{n}}$$

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

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

Where;

n is the total number of points;

X_{Obs}, Y_{Obs}, and Z_{Obs}, are observed coordinates/standard coordinates of point ***i***; and

X_{Proc}, Y_{Proc}, *and* Z_{Proc}, are processed coordinates of point ***i***.

The smaller the value of the root mean square error estimate the better the accuracy attainable with the 3D coordinates obtained from the Online GNSS processing services. The comparisons between obtained results, i.e., observed coordinates and processed coordinates were presented in tabular form as shown in the tables below;

Table 1: RMSE in X-coordinate for AUSPOS

Point	X_{Obs}	X_{Proc}	$(X_{Obs} - X_{Proc})$	$(X_{Obs} - X_{Proc})^2$
G16/028	736364.011	736364.036	-0.025	0.000625
G16/029	736451.450	736451.438	0.012	0.000144
G16/030	736582.252	736582.270	-0.018	0.000324
G16/031	736690.773	736690.752	0.021	0.000441
G16/032	736779.842	736779.868	-0.026	0.000676
G16/033	736888.867	736888.836	0.031	0.000961
G16/034	737020.218	737020.184	0.034	0.001156
***rmsX* = 0.0249m = 2.49cm**				

Table 2: RMSE in Y-coordinate for AUSPOS

Point	Y_{Obs}	Y_{Proc}	$(Y_{Obs} - Y_{Proc})$	$(Y_{Obs} - Y_{Proc})^2$
G16/028	807597.226	807597.209	0.017	0.000289
G16/029	807469.090	807469.109	-0.019	0.000361
G16/030	807336.859	807336.839	0.020	0.000400
G16/031	807178.728	807178.758	-0.030	0.000900
G16/032	807090.978	807090.956	0.022	0.000484
G16/033	806966.644	806966.616	0.028	0.000784
G16/034	806956.678	806956.654	0.024	0.000576
***rmsY* = 0.0233m = 2.33cm**				

Table 3: RMSE in Z-coordinate for AUSPOS

Point	Z_{Obs}	Z_{Proc}	$(Z_{Obs} - Z_{Proc})$	$(Z_{Obs} - Z_{Proc})^2$
G16/028	376.441	376.474	-0.033	0.001089
G16/029	371.516	371.490	0.026	0.000676
G16/030	365.133	365.112	0.021	0.000441
G16/031	360.384	360.364	0.020	0.000400
G16/032	358.078	358.095	-0.017	0.000289
G16/033	356.821	356.846	-0.025	0.000625
G16/034	358.944	358.921	0.023	0.000529
***rmsZ* = 0.0241m = 2.41cm**				

Table 4: RMSE in X-coordinate for CSRS-PPP

Point	X_{Obs}	X_{Proc}	$(X_{Obs} - X_{Proc})$	$(X_{Obs} - X_{Proc})^2$
G16/028	736364.011	736364.036	-0.025	0.000625
G16/029	736451.450	736451.483	-0.033	0.001089
G16/030	736582.252	736582.273	-0.021	0.000441
G16/031	736690.773	736690.816	-0.043	0.001849
G16/032	736779.842	736779.815	0.027	0.000729
G16/033	736888.867	736888.830	0.037	0.001369
G16/034	737020.218	737020.176	0.042	0.001764
***rmsX* = 0.0335m = 3.35cm**				

Table 5: RMSE in Y-coordinate for CSRS-PPP

Point	Y_{Obs}	Y_{Proc}	$(Y_{Obs} - Y_{Proc})$	$(Y_{Obs} - Y_{Proc})^2$
G16/028	807597.226	807597.266	-0.040	0.001600

G16/029	807469.090	807469.041	0.049	0.002401
G16/030	807336.859	807336.833	0.026	0.000676
G16/031	807178.728	807178.760	-0.032	0.001024
G16/032	807090.978	807090.947	0.031	0.000961
G16/033	806966.644	806966.680	-0.036	0.001296
G16/034	806956.678	806956.640	0.038	0.001444
***rmsY* = 0.0367m = 3.67cm**				

Table 6: RMSE in Z-coordinate for CSRS-PPP

Point	Z_{Obs}	Z_{Proc}	$(Z_{Obs} - Z_{Proc})$	$(Z_{Obs} - Z_{Proc})^2$
G16/028	376.441	376.413	0.028	0.000784
G16/029	371.516	371.477	0.039	0.001521
G16/030	365.133	365.167	-0.034	0.001156
G16/031	360.384	360.405	-0.021	0.000441
G16/032	358.078	358.043	0.035	0.001225
G16/033	356.821	356.852	-0.031	0.000961
G16/034	358.944	358.976	-0.032	0.001024
***rmsZ* = 0.0319m = 3.19cm**				

Table 7: RMSE in X-coordinate for MagicGNSS/PPP

Point	X_{Obs}	X_{Proc}	$(X_{Obs} - X_{Proc})$	$(X_{Obs} - X_{Proc})^2$
G16/028	736364.011	736364.052	-0.041	0.001681
G16/029	736451.450	736451.475	-0.025	0.000625
G16/030	736582.252	736582.282	-0.030	0.000900
G16/031	736690.773	736690.825	-0.052	0.002704
G16/032	736779.842	736779.832	0.010	0.000100
G16/033	736888.867	736888.805	0.062	0.003844
G16/034	737020.218	737020.168	0.050	0.002500
***rmsX* = 0.0420m = 4.20cm**				

Table 8: RMSE in Y-coordinate for MagicGNSS/PPP

Point	Y_{Obs}	Y_{Proc}	$(Y_{Obs} - Y_{Proc})$	$(Y_{Obs} - Y_{Proc})^2$
G16/028	807597.226	807597.285	-0.059	0.003481
G16/029	807469.090	807469.052	0.038	0.001444
G16/030	807336.859	807336.831	0.028	0.000784
G16/031	807178.728	807178.751	-0.023	0.000529
G16/032	807090.978	807090.963	0.015	0.000225

G16/033	806966.644	806966.672	-0.028	0.000784
G16/034	806956.678	806956.635	0.043	0.001849
***rmsY* = 0.0360m = 3.60cm**				

Table 9: RMSE in Z-coordinate for MagicGNSS/PPP

Point	Z_{Obs}	Z_{Proc}	$(Z_{Obs} - Z_{Proc})$	$(Z_{Obs} - Z_{Proc})^2$
G16/028	376.441	376.422	0.019	0.000361
G16/029	371.516	371.471	0.045	0.002025
G16/030	365.133	365.182	-0.049	0.002401
G16/031	360.384	360.417	-0.033	0.001089
G16/032	358.078	358.061	0.017	0.000289
G16/033	356.821	356.86	-0.039	0.001521
G16/034	358.944	358.967	-0.023	0.000529
***rmsZ* = 0.0343m = 3.43cm**				

Table 10: RMSE in X-coordinate for APPS

Point	X_{Obs}	X_{Proc}	$(X_{Obs} - X_{Proc})$	$(X_{Obs} - X_{Proc})^2$
G16/028	736364.011	736363.949	0.062	0.003844
G16/029	736451.450	736451.496	-0.046	0.002116
G16/030	736582.252	736582.282	-0.03	0.000900
G16/031	736690.773	736690.713	0.060	0.003600
G16/032	736779.842	736779.938	-0.096	0.009216
G16/033	736888.867	736888.876	-0.009	0.000081
G16/034	737020.218	737020.335	-0.117	0.013689
***rmsX* = 0.0691m = 6.91cm**				

Table 11: RMSE in Y-coordinate for APPS

Point	Y_{Obs}	Y_{Proc}	$(Y_{Obs} - Y_{Proc})$	$(Y_{Obs} - Y_{Proc})^2$
G16/028	807597.226	807597.269	-0.043	0.001849
G16/029	807469.090	807469.023	0.067	0.004489
G16/030	807336.859	807336.824	0.035	0.001225
G16/031	807178.728	807178.858	-0.130	0.016900
G16/032	807090.978	807090.909	0.069	0.004761
G16/033	806966.644	806966.749	-0.105	0.011025
G16/034	806956.678	806956.641	0.037	0.001369

***rmsY* = 0.0771m = 7.71cm**

Table 12: RMSE in Z-coordinate for APPS

Point	Z_{Obs}	Z_{Proc}	$(Z_{Obs} - Z_{Proc})$	$(Z_{Obs} - Z_{Proc})^2$
G16/028	376.441	376.528	-0.087	0.007569
G16/029	371.516	371.553	-0.037	0.001369
G16/030	365.133	365.225	-0.092	0.008464
G16/031	360.384	360.370	0.014	0.000196
G16/032	358.078	358.089	-0.011	0.000121
G16/033	356.821	356.939	-0.118	0.013924
G16/034	358.944	358.727	0.217	0.047089
***rmsZ* = 0.1061m = 10.61cm**				

Table 13: RMSE in X-coordinate for GAPS

Point	X_{Obs}	X_{Proc}	$(X_{Obs} - X_{Proc})$	$(X_{Obs} - X_{Proc})^2$
G16/028	736364.011	736364.083	-0.072	0.005184
G16/029	736451.450	736451.472	-0.022	0.000484
G16/030	736582.252	736582.271	-0.019	0.000361
G16/031	736690.773	736690.658	0.115	0.013225
G16/032	736779.842	736779.873	-0.031	0.000961
G16/033	736888.867	736888.829	0.038	0.001444
G16/034	737020.218	737020.322	-0.104	0.010816
***rmsX* = 0.0681m = 6.81cm**				

Table 14: RMSE in Y-coordinate for GAPS

Point	Y_{Obs}	Y_{Proc}	$(Y_{Obs} - Y_{Proc})$	$(Y_{Obs} - Y_{Proc})^2$
G16/028	807597.226	807597.259	-0.033	0.001089
G16/029	807469.090	807469.056	0.034	0.001156
G16/030	807336.859	807336.758	0.101	0.010201
G16/031	807178.728	807178.765	-0.037	0.001369
G16/032	807090.978	807090.937	0.041	0.001681
G16/033	806966.644	806966.735	-0.091	0.008281
G16/034	806956.678	806956.542	0.136	0.018496
***rmsY* = 0.0777m = 7.77cm**				

Table 15: RMSE in Z-coordinate for GAPS

Point	Z_{Obs}	Z_{Proc}	$(Z_{Obs} - Z_{Proc})$	$(Z_{Obs} - Z_{Proc})^2$
G16/028	376.441	376.512	-0.071	0.005041
G16/029	371.516	371.532	-0.016	0.000256
G16/030	365.133	365.213	-0.080	0.006400
G16/031	360.384	360.353	0.031	0.000961
G16/032	358.078	358.068	0.010	0.000100
G16/033	356.821	356.925	-0.104	0.010816
G16/034	358.944	358.759	0.185	0.034225
***rmsZ* = 0.0909m = 9.09cm**				

Table 16: Accuracy assessment (Summary of RMSEs of the Online GNSS processing service)

GNSS Processing Software	rmsX (cm)	rmsY (cm)	rmsZ (cm)
AUSPOS	±2.49	±2.33	±2.41
CSRS-PPP	±3.35	±3.67	±3.19
MagicGNSS/PPP	±4.20	±3.60	±3.43
APPS	±6.91	±7.71	±10.61
GAPS	±6.81	±7.77	±9.09

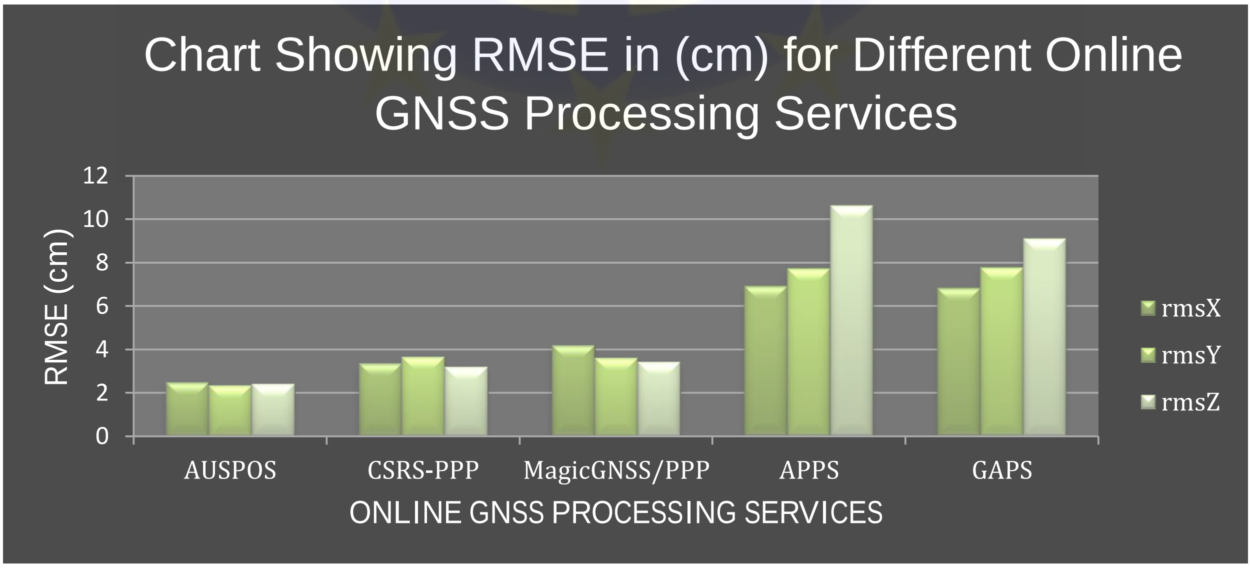

Figure 3: RMSE in (cm) for different GNSS Software based on 1hr observation period

Using insight into Table 16 above, some remarkable points were noted:

a) The root mean square error obtained for AUSPOS online processing service was very small and these can be attributed to its use of scientific processing software.

b) In the X, Y, and Z direction, the best accuracy was obtained from AUSPOS online processing service which employed relative solution approach with the calculated root mean square errors of ±2.49, ±2.33 and ±2.41 in X, Y and Z direction respectively.

c) According to the obtained results, the root mean square error provided by AUSPOS online service was less than that of other services and these can be attributed to the 14 network of IGS reference points used in the processing of the data.

d) According to the obtained results, CSRS-PPP gives better results than other online processing services which employed precise point positioning solution approach with the calculated root mean square error of ±3.35, ±3.67 and ±3.19 in X, Y and Z direction respectively.

e) The maximum error was provided by APPS online service with calculated root mean square deviations of ±6.91, ±7.71 and ±10.61 in the X, Y and Z direction respectively.

8.0 CONCLUSIONS

Many of free online GNSS processing services have been established to provide the user with a reliable solution which helps to reduce the personnel, logistics and equipment costs. Due to the advancement of these online services, they become a superior tool than the historical methods of control network establishment.

In this study, a test study was conducted by considering five (5) online GNSS processing services which are used frequently and widely in the world. For this purpose, the 3D co-ordinates of seven (7) selected control points were determined by using one (1) relative solution approach service and four (4) PPP solution approach services with 1-hour GPS data observation. The true station co-ordinates were obtained by running a closed traverse with total station instrument. The accuracies provided by the services were obtained by comparing online processing service co-ordinates with total station co-ordinates. According to the results, AUSPOS which employed relative positioning service has more reliable results than other services which employed precise point positioning service. CSRS-PPP has the more reliable results among other PPP services. All the online services used in this study provide the final co-ordinates with a precision of a couple of centimeters to a few errors of decimetres which is attributed to the observation time of 1-hour.

However, testing is still needed to evaluate the performance of these services in other areas and to include longer observation sessions.

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