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Global Positioning System Performance Assessment with Precise Point Positioning and Relative Positioning

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Abstract- Global Positioning System (GPS) is a satellite navigation system used to determine the ground position of an object in providing high accuracy in the coordinates. However, relative baseline length and duration of observations can affect the positioning accuracy. Several organizations have developed online Global Navigation Satellite System (GNSS) processing services as an alternative solution to achieve centimeter to decimeter-level accuracy. This study evaluates the positioning performance of the Precise Point Positioning (PPP) – Canadian Spatial Reference System (CSRS), and relative positioning – Australian Online GPS Processing Service (AUSPOS) methods. A commercial software Trimble Business Center version 5.2 (TBC v5.2) as the benchmark processing. The consistency of positioning performance among the online services have been identified in three different areas. These study areas are located along the Pan Borneo Highway, East Malaysia, using the established control points. Different services are presented and compared. CSRS-PPP results show that the mean Root Mean Square Error (RMSE) are 0.039 m of Easting, 0.031 m of Northing, and 0.062 m of Up components, while AUSPOS results are 0.098 m of Easting, 0.037 m of Northing, and 0.073 m of Up components, which centimeter-level is achievable in CSRS-PPP online services. Thus, the overall results suggest that CSRS-PPP online services are more reliable for GPS users in obtaining the high accuracy coordinate in GPS post-processing, especially in engineering purposes.

Keywords - GPS, Precise Point Positioning, Relative Positioning, TBC, Online GPS Processing

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1. Introduction

Global Navigation Satellite System (GNSS) has been used widely around the world, especially in engineering applications, positioning, navigation, and timing systems (Ocalan et al., 2016). It is a broad term used to encompass all global satellite-based navigation systems providing geospatial positioning with global coverage on or near the Earth's surface, and Global Positioning System (GPS) is one of the GNSS components (Jackson et al., 2018). GNSS, together with GPS, are collaborated to provide a precise location on Earth, and both consist of three major segments that are the space segment (satellites), the ground segment (ground control points) and the user segment (GPS receivers) (Maciuk and Rudyk, 2020). The main difference between GPS and GNSS is that GNSS systems are compatible with all satellites from other networks while the GPS is one of the satellites; thus, more satellites will increase receiver accuracy and reliability. The development of various differential techniques can enhance the positioning accuracy where GNSS data processing methodology has improved in technology and offered users accurate positioning (Shi and Wei, 2020). Commonly, most GPS users have used relative positioning techniques to provide high accuracy in the coordinates. Also, it is required fundamental knowledge of the GPS and experience in the processing. Several organizations have developed web-based online services as an alternative solution against the conventional data processing method for reducing the cost to process GPS data. It is essentially user-friendly to achieve the centimetre (cm) to decimetre (cm) level accuracy point positions and useful for GPS users to obtain and evaluate data easily through these online services (El-Mowafy, 2011). It is also easy to use, has unlimited access and has no license requirement on GPS processing (Alkan et al., 2016). Two types of solutions approach can be used for web-based online services to calculate the estimation coordinates: the Precise Point Positioning (PPP) solution approach that acquired the use of a single GPS receiver while the relative (i.e., baseline, network) solution approach requires at least two receivers and one receiver must be a known station. Despite PPP using a single station, the processing parameter is still in relative PPP purpose. PPP should be standalone without requiring information on the network. In this case, PPP is not an absolute solution but relies on a global solution (Odijk et al., 2016).

According to Tata et al. (2020), the online services produced the results with a few cm values by comparing the commercial software with an observation period of one (1) hour for three (3) consecutive days. Tata et al. (2020) found that both online services are acceptable by taking a longer time period. Besides, Aziz (2018) investigated the baseline length obtained using online services and compared it with the baseline length computed by the relative solution using TBC at different observation times of 1, 2, 3 and 4 hours. Throughout the research, the relative GPS using TBC software gave better results at all observation times. In addition, Tariq et al. (2017) investigated the duration of observations for each point was measured into five periods (2-hour, 4-hour, 6-hour, 8-hour, and 10-hour) for three online services (OPUS, AUSPOS and CSRS-PPP) and one post-processing software (LGO v8.3). It is suggested that the duration of observations must be longer to resolve the ambiguity. Lastly, Ocalan et al. (2016) investigated the accuracy of the PPP method by applying various online processing services and the quality of satellite ephemerides products used for data evaluation (ultra-rapid, rapid and final orbits) in three different test-point sites such as free satellite visibility, partially and vastly prevents the satellite signals near or within the forest area for a time span of six (6) hours. The studies were highlighted that the multipath effect could be reduced when the satellite visibility is sufficiently tracked. To achieve the reliable results at mm level, the authors recommended the users to take a longer time span on the duration of GPS observations of 10-hour at an open space area where the multipath effect could be minimized to improve data. However, the baseline length between two receivers must be considered, especially in Malaysia. AUSPOS uses International GNSS Service (IGS) as the reference station, and there are only three IGS stations (NTUS, PTAG, and PIMO) in the Southeast Asia region. The GPS carrier phase ambiguity resolution due to the ionosphere can be one of the main obstacles, especially over long baselines of >1,000km (Hernandez-Pajares et al., 2000).

In this contribution, this study determines the reliability of the online processing services for GPS users to explore the precision performance in positioning, which may be suitable for engineering works requiring a centimetre to decimetre level of precision. The experimental work has been tested along Pan Borneo Highway, located in Sarawak, East Malaysia. In this study, three areas are covered from route Sibu-Bintulu and these control points are used in the relative positioning network. In order to determine the reliability of the online processing services of point positioning, three different study areas were examined by establishing Ground Control Points (GCPs), and the duration of observations of all GCPs was performed more than 2 hours with dual-frequency carrier-phase observations in static mode. The study aims to evaluate the accuracy of the PPP and relative positioning approach by using online processing services such as in Canadian Spatial Reference System-PPP (CSRS-PPP) and Australian Online GPS Processing Service (AUSPOS) as a relative network positioning while a commercial software using Trimble Business Center (TBC) as a benchmark processing in three different study areas of Pan Borneo Highway in Sarawak. The aims embark on two (2) objectives: 1) to evaluate the GPS positioning precision level using the online processing services and the commercial software, and 2) to identify the consistency of positioning performance among the online services.

2. Methodology

The research methodology has represented the workflow of the study plan from data acquisition up to data analysis to achieve the research objectives, as shown in Figure 1. It is constructed into five (5) phases; Phase 1 is data collection of GPS observations from the field before importing them into GPS post-processing methods. Phase 2 evaluates the GPS positioning precision level with the PPP and differential techniques using online processing services and commercial software. The coordinate systems synchronization is performed in Phase 3. Phase 4 is the assessment of the positioning performance of PPP and relative processing techniques on different processing platforms. Finally, the results were interpreted based on Root Mean Square Error (RMSE) in Phase 5.

Prior to GPS post-processing, GPS observations data were collected from the field in relative static mode for more than 2 hours with dual-frequency carrier-phase observations using GPS receivers called Spectral Precision instrument SP80. According to Tata et al. (2020), the duration of GPS observations of more than 2 hours could enhance the quality of data collected for reliable results in an accurate sense. Twenty-nine (29) GCPs were established and it have been set up in open space areas to better satellite visibility and minimize the multipath effect in order to investigate the accuracy of the relative and PPP methods. The time-spanning data of observations started from 22nd April to 27th April 2021 or Day of Year (DoY) 112-2021 until 117-2021.

Once the data observations have been collected, the GPS raw data are converted into RINEX Version 3.02 by exporting all GCPs to the RINEX Converter as per the requirements of both online processing services. Two types of solutions approach to evaluate the online processing services: AUSPOS and CSRS-PPP. Basically, the users send the RINEX files by uploading the files to the website, and then the estimated coordinates results will be resent back to the user via email. However, commercial software such as Trimble Business Center (TBC) could be used as the benchmark of processing where the baseline networks were computed during data processing which eliminate systematic errors in the network to obtain the final coordinates. Note that the reference system in TBC has been mapped in ITRF2014 epoch 2010.0 in order to equivalent the reference frame of the online processing services for comparing the positioning accuracy.

Next, the estimated coordinates in the WGS84 (G2139) geodetic datum must be converted from a 3D cartesian coordinate system (X, Y and Z) into the 3D geographical coordinate system (latitude ϕ, longitude λ, and ellipsoidal height h) via datum transformation for synchronizing coordinate systems (Kelly and Dennis, 2022). Later, the 3D geographical coordinate system was converted to the local topocentric coordinate (Easting, Northing and Up) to fix local points on the Earth surface via map projection. The coordinate conversion of topocentric coordinates was processed through Matlab (R2021a) software for both estimated coordinates and their differences have been calculated for all components in Easting, Northing, and Up, as shown by Equations (1) – (3).

Coordinate difference Easting (ΔE) = $(E_{estimated,i} - E_{known,i})$ Equation (1)

Coordinate difference Northing (ΔN) = $(N_{estimated,i} - N_{known,i})$ Equation (2)

Coordinate difference Up (ΔU) = $(U_{estimated,i} - U_{known,i})$ Equation (3)

where;
ΔE is Easting differences
ΔN is Northing differences
ΔU is Up differences.

Finally, the assessment of positioning performance of PPP and relative processing techniques can be obtained through Root Mean Square Error (RMSE). RMSE is often used to measure the difference between observed values and known values from a different set of measurements. It indicates the measurement of accuracy differences relative to the known coordinates for the total number of stations. For instance, the differences between AUSPOS estimated coordinates and known coordinates in Easting had been defined as the square root of mean squared error over the total number of stations. Hence, the calculation of RMSE for Northing and Up should be applied the same formula as Easting as shown in Equation (4). The same procedures of RMSE calculations for Easting, Northing and Up components were also applied to CSRS-PPP for three areas to evaluate the precision coordinate. In order to identify the consistency of the positioning performance, the most probable values were calculated based on RMSE for AUSPOS and CSRS-PPP.

$$\text{RMSE Easting} = \sqrt{\frac{\sum_{i=1}^{n}(E_{estimated,i} - E_{known,i})^2}{n}} \qquad \text{Equation (4)}$$

where;

n is the total number of stations

$E_{estimated}$, $N_{estimated}$, $U_{estimated}$ are estimated local topocentric coordinates of station i from online processing services

E_{known}, N_{known}, U_{known} are processed known coordinates of the station i from commercial software (TBC).

3. Results and Discussion

According to Ocalan et al. (2016), the commercial software is used for a short baseline which could be useful for the relative approach technique by generating interpolation between independent stations to achieve high accuracy on the results. However, web-based online processing services could produce faster results, but the precision coordinates depend in certain areas, especially in Malaysia, where water vapour could induce a significant amount of the tropospheric delay as well as the length of baseline (Musa et al., 2011). Since AUSPOS uses GPS-only observation, this could be some factor during GPS post-processing. CSRS-PPP (PPP) can make GPS users desire to select which satellite constellation, such as GPS-only, GLONASS-only or GPS+GLONASS. The use of multi-GNSS satellite observations in GPS post-processing could be an advantage due to the increase in the number of observations. This is not the unique parameter to improve the point positioning accuracy in post-processing. However, AUSPOS is expected to be slightly different when using GPS-only to PPP method due to the different frequencies between satellites. In commercial software such as TBC, the satellite vision can manually select the multi-constellation of satellite in the project setting such as GPS, GLONASS, Galileo, Beidou and QZSS. Consequently, the satellite constellations are using GPS-only in this study.

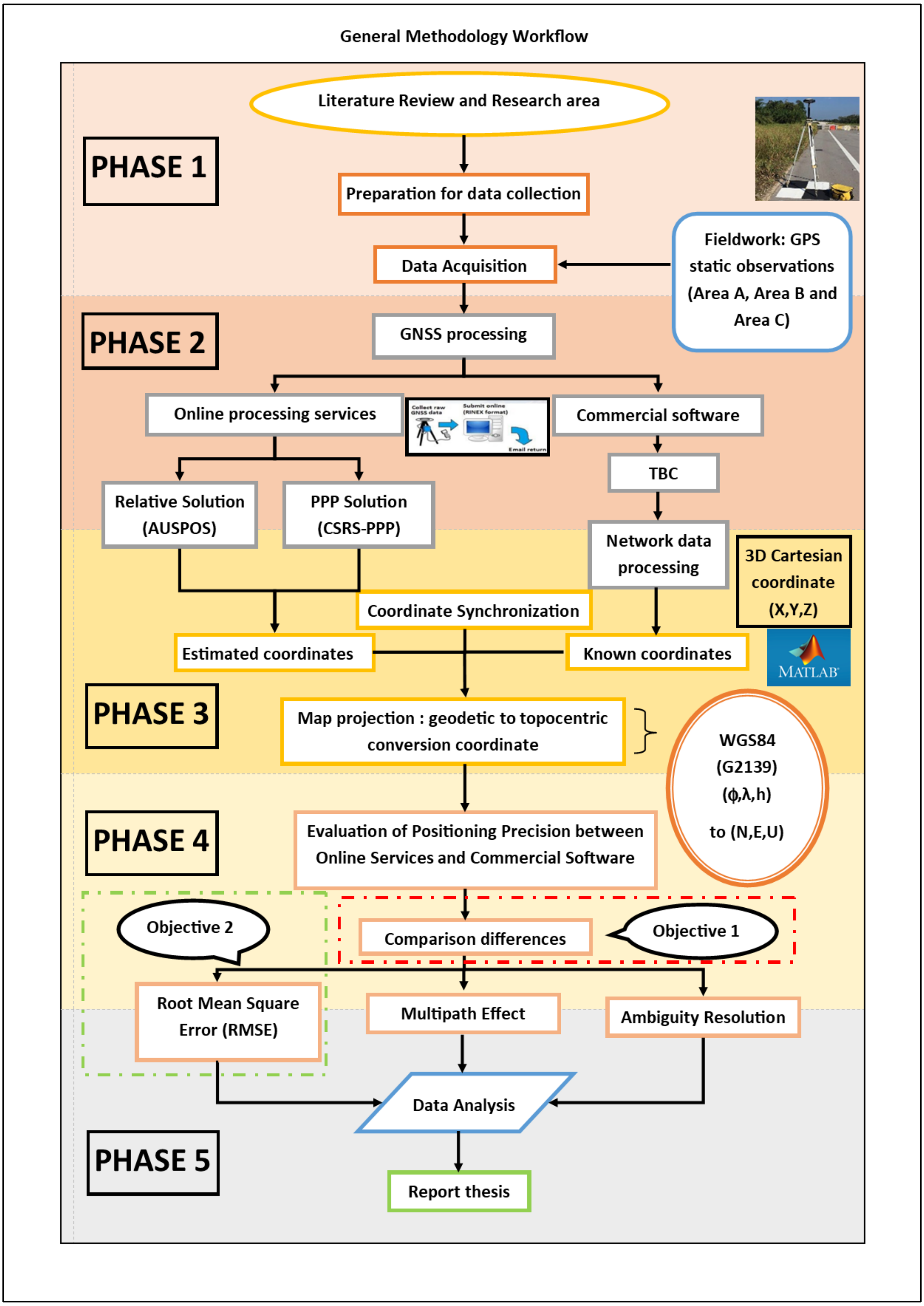

Figure 1: The workflow of research methodology.

3.1 Evaluation of positioning precision between online processing services and commercial software

Both relative solution and PPP solution in the online services were used to compute GCPs using IGS and clock products (Ocalan et al., 2016). These coordinates and standard deviations were obtained from online services as well as from commercial software. Standard deviation is a statistical measuring tool with a variability of a numerical dataset. The lower the standard deviation values, the closer the data to the mean. The final coordinates were displayed the standard deviation with sigma 95% for both online services and commercial software. In order to get the mean of standard deviations, the averaged points were calculated accordingly for every GCPs. Table 1 below shows the mean standard deviations of the coordinates between Area A, Area B and Area C. The mean standard deviations of the coordinates are small in Easting and Northing components from about 10 mm to 13 mm, especially for relative solution in TBC v5.2 software. Also, Area B proves that the relative solution in TBC v5.2 software has small standard deviations of coordinates. Hence, TBC acts as the benchmark processing to evaluate the online processing services by applying Equation (1). The solution estimated manually by commercial software indicates the differences computed with TBC v5.2 software. This proves that the quality of positioning performance is good in accordance with commercial software.

Table 1: Mean standard deviation of the coordinate differences for Areas A, B and C.

	σE (m)	**σN (m)**	**σU (m)**
	Area A		
TBC	0.010	0.013	0.052
AUSPOS	0.071	0.021	0.084
CSRS-PPP	0.046	0.018	0.068
	Area B		
TBC	0.009	0.012	0.017
AUSPOS	0.069	0.023	0.085
CSRS-PPP	0.054	0.015	0.065
	Area C		
TBC	0.002	0.002	0.005
AUSPOS	0.029	0.009	0.032
CSRS-PPP	0.018	0.006	0.022

The results obtained from this study are that the coordinates of twelve (12) GCPs were compared to determine their relative discrepancies and accuracies based on the local topocentric coordinates. The RMSE were also calculated to measure the differences between two data sets. Table 2 compares the estimated coordinates of AUSPOS relative solution and CSRS-PPP solution from the differences of known coordinates in TBC, which acts as the benchmark processing for the area in Area A. The RMSE has smaller values in CSRS-PPP of 2 cm, 5 cm and 9 cm, compared to AUSPOS of 11 cm, 5 cm and 11 cm in Easting, North and Up, respectively. This result indicates that CSRS-PPP has achieved a better solution precision than AUSPOS. However, the Up component was almost a decimetre (approx. 9 cm), but the planimetric coordinates results were promising since it is suitable for engineering purposes. On the other hand, GCP06 has poor geometry in the network, as it has been observed with one receiver on that day. As shown in Table 2, GCP06 of Area A indicates the worst values of coordinate differences for both online processing such that AUSPOS showed 17 cm in Easting, -8 cm in Northing, and -23 cm in Up component, whereas CSRS-PPP showed -3 cm in Easting, 6 cm in Northing and 17 cm in Up components.

This GCP has only relied on the reference station (CORS) network, which affects the position quality in network distribution. The network has a weaker solution because it cannot be adjusted with other stations; hence, it is called an independent session. This could be one of the factors that affect the coordinate differences. Hence, the GCP needs to be a loop to each other without any gaps in the session in order to strengthen the network geometry. The coordinates position is stronger when having more GCPs correlated to each other. Overall, these areas indicate similar precision for every independent dataset. Nevertheless, it is a good sign as these online services have a similar pattern in coordinate differences-wise. Thus, results can be reliable if all datasets have the same position precision.

Table 2: Comparison between estimated coordinate of online services from differences of known coordinate in TBC. GCP06 at Area A is highlighted due to large coordinate differences.

		AUSPOS-TBC			**CSRS-TBC**		
	ID	E (m)	N (m)	U (m)	E (m)	N (m)	U (m)
Area A	GCP01	0.053	0.028	0.091	0.005	0.014	0.048
	GCP02	0.069	0.050	0.080	0.011	0.031	0.092
	GCP03	0.105	0.050	0.062	0.018	0.037	0.097
	GCP04	0.172	0.036	0.098	0.033	0.032	0.059
	GCP05	0.103	0.024	0.034	0.008	0.015	0.039
	∗GCP06	0.174	-0.076	-0.225	-0.025	0.061	0.169
	GCP07	0.034	0.015	0.064	0.005	0.019	0.072
	GCP08	0.111	0.048	0.140	0.028	0.035	0.110
	GCP09	0.094	0.036	0.076	0.020	0.035	0.076
	GCP10	0.094	0.079	0.082	0.045	0.076	0.079
	GCP11	0.139	0.081	0.097	0.030	0.077	0.097
	GCP12	0.080	0.070	0.079	0.015	0.068	0.075
	RMSE	0.102	0.051	0.086	0.023	0.046	0.080
Area B	GCP01	0.050	0.013	0.012	0.019	0.023	0.045
	GCP02	0.140	0.000	-0.014	-0.014	0.014	0.038
	GCP03	0.047	0.065	0.146	0.050	0.036	0.057
	GCP04	0.126	0.003	0.008	0.058	0.020	0.046
	GCP05	-0.043	0.001	-0.019	-0.114	0.028	0.035
	GCP06	0.047	0.026	-0.007	0.041	-0.024	-0.127
	GCP07	0.098	-0.002	0.068	0.043	-0.013	0.028
	GCP08	0.032	0.022	0.080	0.042	0.018	0.058
	RMSE	0.083	0.026	0.064	0.056	0.023	0.062
Area C	GCP01	0.051	0.017	0.068	0.018	0.005	0.036
	GCP02	0.108	-0.086	-0.176	0.051	-0.017	-0.090
	GCP03	0.165	-0.017	-0.023	0.069	-0.027	-0.063
	GCP04	-0.076	-0.023	0.035	0.062	-0.051	-0.049
	GCP05	0.087	-0.029	-0.017	0.021	-0.030	0.002
	GCP06	0.078	-0.019	-0.013	-0.003	-0.017	0.007
	GCP07	0.133	-0.004	-0.009	0.033	0.000	0.030
	GCP08	-0.089	0.001	0.054	-0.002	-0.012	0.009

	GCP09	0.148	0.017	0.040	0.026	0.004	0.022
	RMSE	0.110	0.033	0.069	0.039	0.024	0.022

Note: *** GCP06** is excluded from the RMSE calculation as an outlier; however, it will be discussed in Section 3.2.

3.2 Satellite visibility

Satellite vision in GPS surveying has significant importance for the accuracy of the estimated coordinates. The constraint has been encountered especially performing the GPS observations near the forested area. The location of GCPs is mostly located alongside Pan Borneo Highway in order to reduce the multipath effect. By performing this practice, the satellite vision will be able to track as much as signals from the antenna of the GPS instrument. Considering the total number of satellites used, the increasing of elevation cut-off angle (10° to 15°) can improve the ambiguity resolution. Also, the PDOP value can be used to expect positional accuracy. The multipath effect commonly occurs from the reflective surfaces in the surrounding of the GPS antenna.

According to the results in TBC, GDOP at GCP06 is poor which due to poor satellite geometry. All satellites are using GPS-only with dual-frequency L1+L2 carrier phase observations. During data acquisition, the receivers have been set to a 10° elevation cut-off angle for improving the ambiguity resolution, and the data would not be observed below than 10° elevation cut-off. Static post-processing of RTKPost from RTKlib software can be used to assess the quality of RINEX observation data and to assist in signal quality of satellites. Figure 2 shows the multipath skyplot of GCP06 obtained from RTKlib software for Area A. Signal to Noise Ratio (SNR) is a key parameter of satellite sensor which quantifies how much the signals are corrupted by noise (Qian, 2011). GCP06 has proved that it showed poor signal quality at G31, which indicates the orange colour (< 30 value) for SNR. In order to compare the quality of the signal, GCP07 has been compared as the coordinate differences have better than GCP06. Generally, the low elevation mask is preferably 10° to 15° for a better result in the height component. The accuracy of the initial antenna position and the distance depends on the accuracy of the elevation angles.

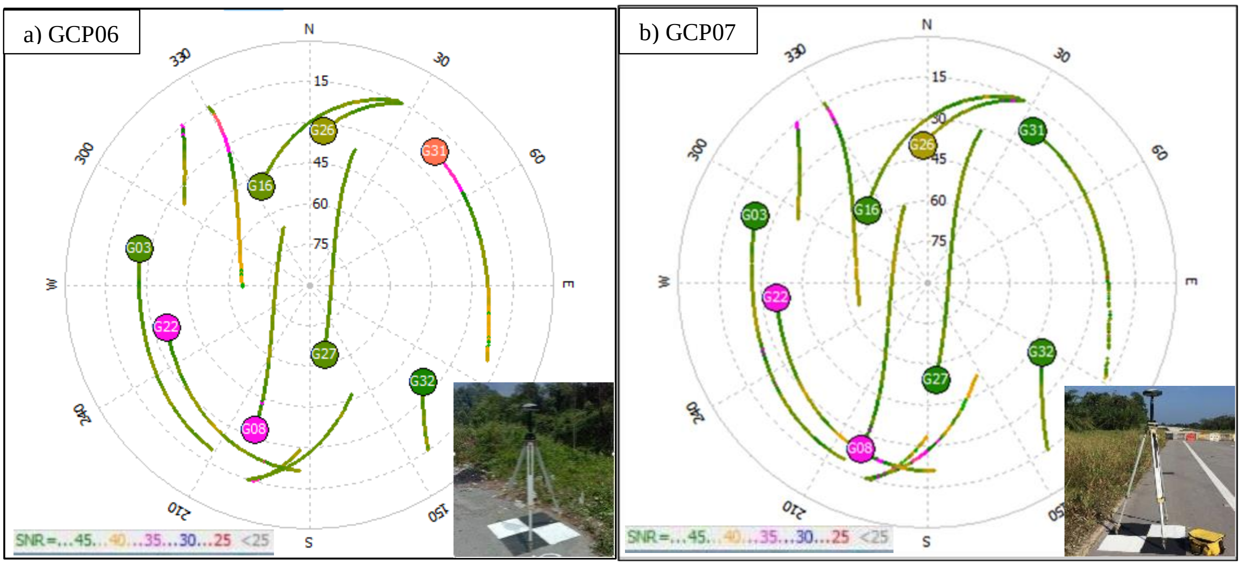

Figure 2: Condition of multipath skyplot for a) GCP06 and b) GCP07 in Area A. GCP06 is set closer to the forested area while GCP07 is set in open space area.

Figure 2 shows the multipath skyplot of GCP07 that displayed dark green at G31, which means the signal quality is good (> 45 value of SNR) as well as to other satellites. In addition, the distance between GCP06 and GCP07 is not too far (approx. 40m), but with two different site environments, the multipath condition could take place in this case. Different observation times (sessions) will give different satellites constellation. For instance, GCP06 was observed from 12 pm to 2 pm, while GCP07 was observed from 8 am to 10 am. Different period shows different geometry of satellites which affect the observation times. In this case, the multipath signal is less at GCP07 on that period of time. Note that GPS has an orbital cycle of 23 hours and 56 minutes which the same satellites will orbit to the same position every day (Axelrad et al., 2005). Since trees surround GCP06, the multipath effect could reduce satellite visibility and block low elevation signals, causing the satellite geometry to deteriorate from satellite obstruction. The low elevation signals are likely to produce an error to the height component, especially in horizontal accuracy and the receiver clock error (Zimmermann et al., 2017). Thus, the site selection is crucial to consider the quality of GPS observation by avoiding reflecting surfaces in the surrounding of the antenna. Ideally, it is suggested that the position dilution of precision values (PDOP) is less than three values, indicating a good geometry if no significant multipath has occurred for best position fixing (Hofmann-Wellenhof et al., 2008).

3.3 Baseline length affects ambiguity resolution

Due to atmospheric delay, satellite orbit and clock correction in GPS positioning, this will significantly affect the positioning performance in coordinates (Santerre and Geiger, 2018). Consequently, the unknown integer number of carrier cycles called ambiguity must be estimated by fixing the carrier-phase observation. The integer carrier-phase ambiguities need to be resolved in order to facilitate precise positioning (Verhagen et al., 2011). According to Table 2, AUSPOS showed a slightly high RMSE in decimetre level accuracy compared to CSRS-PPP. As shown in Figure 3, the location for the IGS station is quite far from Malaysia (approx. 3,500km), where mostly these reference stations are located in Australia and a few stations are located in the SEA region. A map projection below shows a geometry of the network of IGS station location. It shows that the map is skewed heavily toward Australia, and it depicts a poor geometry distribution in AUSPOS processing. Generally, a relative solution is better than a PPP solution, but, in this case, ambiguity resolution would be the main factor to explain the poorer estimated coordinates results of AUSPOS.

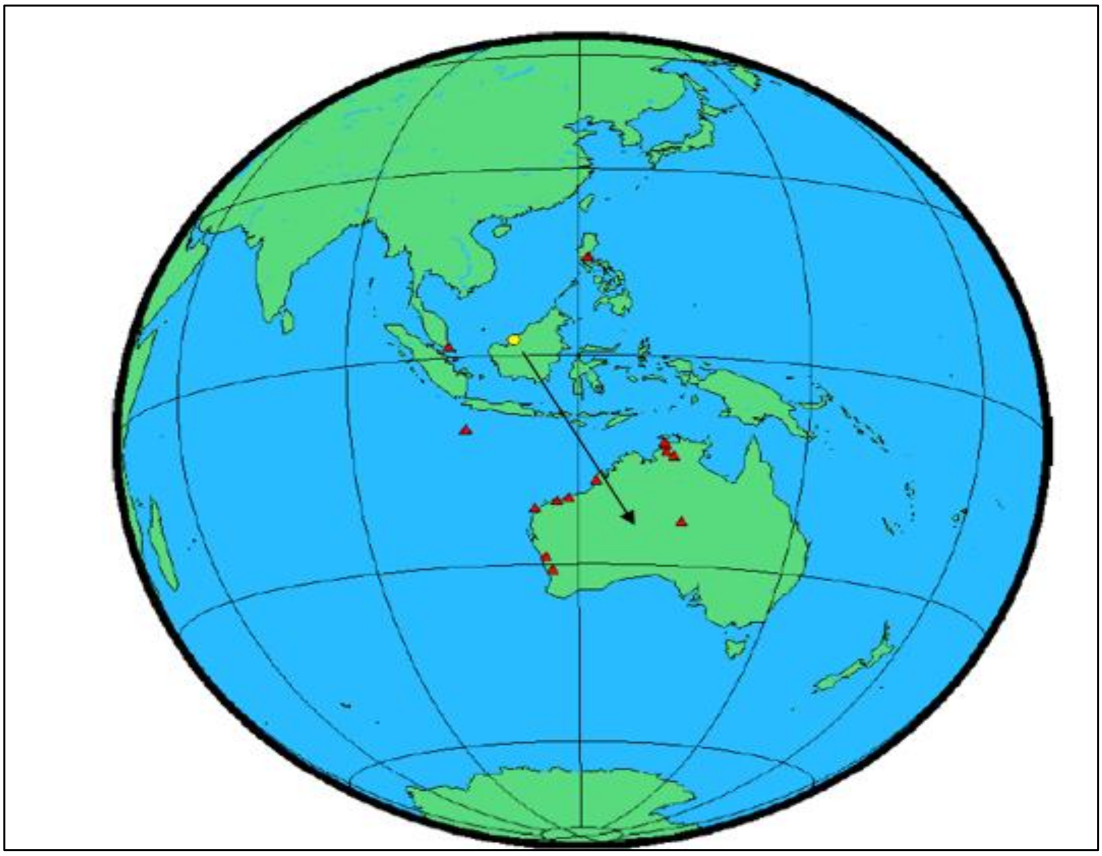

Figure 3: Location of IGS stations (in red triangles) relative to the Malaysian site (in a yellow square) used in this study.

According to the results obtained from the AUSPOS report, ambiguity resolution at GCP06 and GCP07 are compared, and GCP07 has shown better results which are only resolved by 25% ambiguity resolution, while GCP06 has shown 0% ambiguity resolution that seems to worsen the coordinate differences. As we are using the dual-frequency GPS model, the integer ambiguity resolution becomes too weak and is often referred to as the 'ionosphere float' model, which needs a much longer time to be successful. In other words, the presence of differential ionospheric delays is hampered fast ambiguity resolution as using on current GPS dual-frequency model for such a long baseline (Odijk and Teunissen, 2014). The ambiguity resolution success rate of 50% indicates a reliable solution in order to get cm to mm level accuracy. This case shows that a good solution even with 25% is sufficient to get close to cm to dm level accuracy with such a long baseline. Note that three out of 14 is the nearest IGS stations placed in the SEA region, and this indicates the geometry distribution is poor for AUSPOS services as it provides two (2) stations at the Northern part of the map. The closest station to Malaysia is NTUS, located in Singapore with a baseline distance of ~900 km, and ambiguities are resolved depending on this station for data processing. In other words, other baseline lengths only rely on the IGS stations in Australia. Hence, ambiguity resolution, baseline length and geometry of the control stations restricted AUSPOS from achieving better results in this case.

3.4 Reliability of online processing services

Figure 4 presents the bar chart of the mean from a comparison between AUSPOS and CSRS-PPP in order to fulfil the second objective in this study. This showed the results of the mean obtained from Area A, Area B and Area C. These GCPs have been tested to identify the consistency of the coordinates among three different sites of location in order to determine the changes of coordinates component. The results from AUSPOS obtained the highest RMSE in Easting of 10 cm, followed by the Up component of 7 cm. It showed that Easting and Up components in AUSPOS have proved that the long baseline length has worsened the AUSPOS position precision as the reference station selections with more than 1,000 km baseline from Australia. Moreover, AUSPOS relies on the station-dependent estimated processing parameter, and these can be attributed to the 14 International GNSS Service (IGS) reference stations used in processing the data located in Australia (Tata et al., 2020).

On the other hand, CSRS-PPP results showed better results than AUSPOS, which employed a PPP solution approach with the calculated RMSE of 4 cm Easting, 3 cm Northing and 6 cm Up component. In this case, CSRS-PPP used global processing parameters to resolve the ambiguity and requires corrections to reduce the satellite orbit and clock errors to determine precision coordinates. Since it requires a single receiver, the baseline GPS processing is not required to generate the network GPS coordinates. So, the observed points are only derived relative to the satellites but not relative to a reference station (Jamieson and Gillins, 2018). Hence, PPP is still relative to ascertain the network in estimating the position. It cannot be standalone based on measuring the satellites. These global processing parameters include atmospheric corrections, satellite orbits, and clock errors are relative to the network. Hence, PPP is more suitable for estimating position precision which obtained cm-level accuracy in this study.

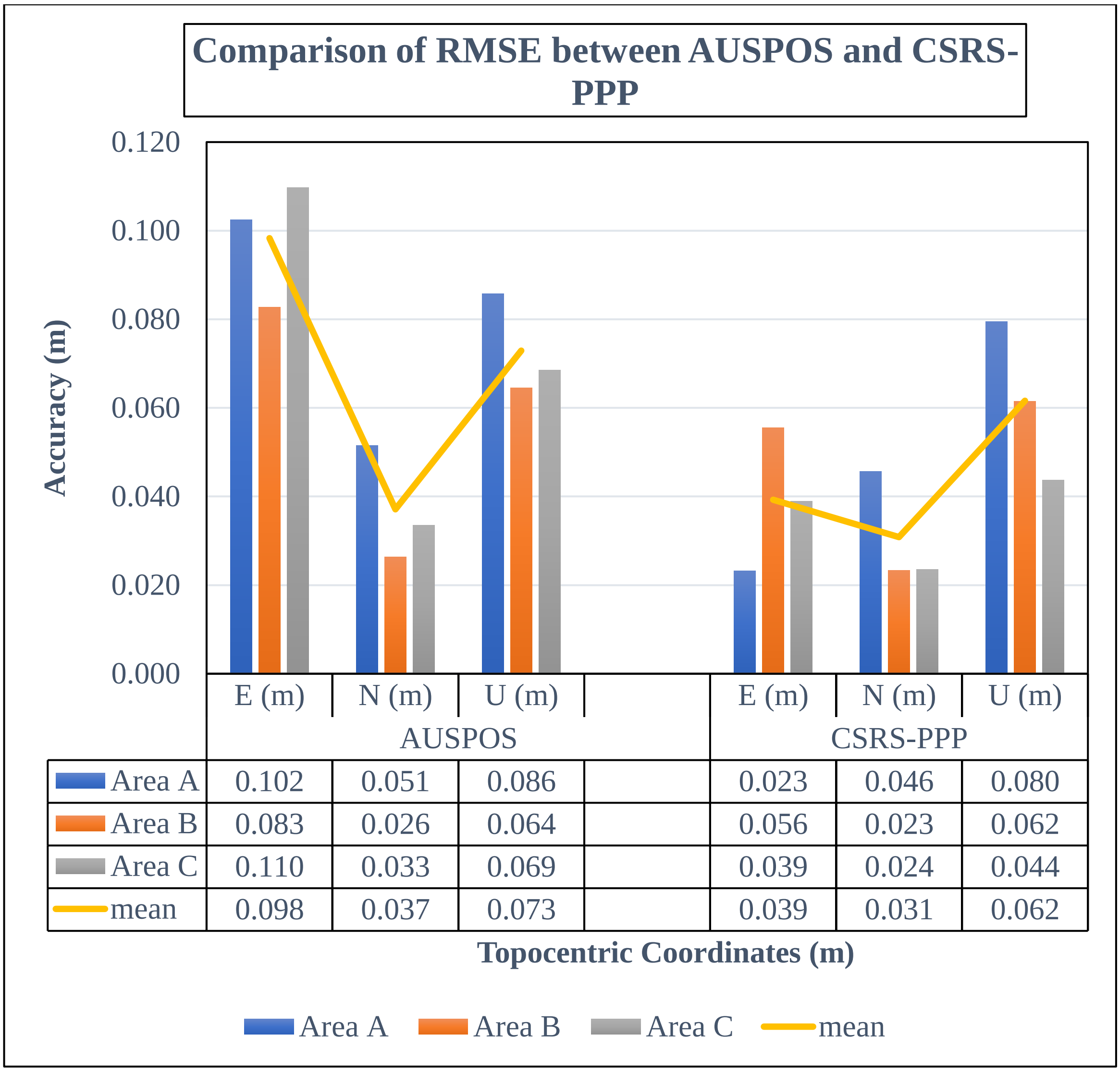

Figure 4: Comparison of RMSE between AUSPOS and CSRS-PPP

4. Conclusion

GPS online post-processing data has become popular nowadays as it is free and makes it easy for users to obtain the estimated coordinates results. All usage of online services is very straightforward, and the users can save time and be cost-effective. So, online processing services will be alternative tools for GPS post-processing in time and budget-saving. As the study is expected to determine how reliable the online services for GPS users obtain the high accuracy of coordinate in GPS post-processing, the results have been achieved in centimetres to decimetres-level accuracy with only a single receiver for all GCPs in this study. Furthermore, the establishment of GCPs is required at least 2 hours of the duration of observations to obtain high precision coordinates and resolve the ambiguity resolution from dual-frequency carrier-phase observations. The location of GCPs should be in open space areas for the visibility of satellite track sufficiently in order to reduce the multipath effect. This shows the benefits of online processing services such as AUSPOS relative positioning and CSRS-PPP, which is available for global use, especially in engineering applications.

Theoretically, relative positioning has better accuracy than the PPP solution. However, in this case, the PPP solution has achieved better than the relative solution without requiring data from any reference stations for simultaneous observation. A decimeter position precision is expected in relative positioning, and especially the baseline length is >1,000km in the case of AUSPOS. Hence, AUSPOS relative positioning is not recommended in Malaysia in terms of high precision due to a limited number of reference stations in the SEA region. Increasing the number of IGS stations will improve the ambiguity resolution for AUSPOS processing. However, both online services are able to produce final coordinates at the accuracy of a few centimetres to decimetres which can be applied in engineering applications such as construction works, setting out the alignment and as-built surveys jobs.

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References

Alkan, R. M., Ilci, V.and Ozulu, I. M. 2016. "*Web-based GNSS data processing services as an alternative to conventional processing technique"*. In FIG Working Week, 1-35.

Axelrad, P., Larson, K. and Jones, B. 2005. *"Use of the correct satellite repeat period to characterize and reduce site-specific multipath errors"*. In Proceedings of the 18th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2005), 2638-2648.

Aziz, K. M. A. 2018. *"Accuracy assessment of free web-based online GPS processing services and relative GPS solution software"*. Journal of Geomatics, 12(1), 82-88.

El-Mowafy, A. 2011. *"Analysis of web-based GNSS post-processing services for static and kinematic positioning using short data spans"*. Survey review, 43(323), 535-549.

Hernández-Pajares, M., Juan, J. M., Sanz, J. and Colombo, O. L. 2000. *"Application of ionospheric tomography to real-time GPS carrier-phase ambiguities resolution, at scales of 400–1000 km and with high geomagnetic activity"*. Geophysical Research Letters, 27(13), 2009-2012.

Hofmann-Wellenhof, B., Lichtenegger, H. and Wasle, E. 2008. *"GPS. GNSS—Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more"*. 309-340.

Jackson, J., Saborio, R., Ghazanfar, S. A., Gebre-Egziabher, D. and Davis, B. 2018. *"Evaluation of low-cost, centimeter-level accuracy OEM GNSS receivers"*. Minnesota Department of Transportation. Research report. 1-55.

Jamieson, M. and Gillins, D. T. 2018. *"Comparative analysis of online static GNSS post-processing services"*. Journal of surveying engineering, 144(4).

Kelly, K. M. and Dennis, M. L. 2022. *"Transforming between WGS84 realizations"*. Journal of Surveying Engineering, 148(2), 04021031.

Maciuk, K. and Rudyk, Y. 2020. *"Usage of the global navigation satellite systems in safety and protection issues"*. Zeszyty Naukowe. Transport/Politechnika Śląska.

Musa, T. A., Amir, S., Othman, R., Ses, S., Omar, K., Abdullah, K., and Rizos, C. 2011. *"GPS meteorology in a low-latitude region: Remote sensing of atmospheric water vapor over the Malaysian Peninsula"*. Journal of atmospheric and solar-terrestrial physics, 73(16), 2410-2422.

Ocalan, T., Erdogan, B., Tunalioglu, N., and Durdag, U. M. 2016. *"Accuracy investigation of PPP method versus relative positioning using different satellite ephemerides products near/under forest environment"*. Earth sciences research journal, 20(4), 1-9.

Odijk, D., Zhang, B., Khodabandeh, A., Odolinski, R., and Teunissen, P. J. G. 2016. *"On the estimability of parameters in undifferenced, uncombined GNSS network and PPP-RTK user models by means of S-system theory"*. Journal of Geodesy, 90(1), 15-44.

Odijk, D., Arora, B. S., and Teunissen, P. J. 2014. *"Predicting the success rate of long-baseline GPS+ Galileo (partial) ambiguity resolution"*. The journal of navigation, 67(3), 385-401.

Qian, S. E. 2011. *"Enhancing space-based signal-to-noise ratios without redesigning the satellite"*. SPIE Newsroom.

Santerre, R., and Geiger, A. 2018. *"Geometry of GPS relative positioning"*. GPS Solutions, 22(2), 1-14.

Shi, C., and Wei, N. 2020. *"Satellite navigation for digital earth"*. In Manual of Digital Earth, 125-160.

Tariq, M., Abduhaq, H., and Husham, H. 2017. *"Accuracy assessment of different GNSS processing software"*. Imperial Journal of Interdisciplinary Research (IJIR), 3(10).

Tata, H., Nzelibe, I. U. and Raufu, I. O. 2020. *"Assessing the Accuracy of Online GNSS Processing Services and Commercial Software"*. South African Journal of Geomatics, 9(2), 321-332.

Verhagen, S., Teunissen, P. J., van der Marel, H., and Li, B. 2011. *"GNSS ambiguity resolution: which subset to fix"*. In IGNSS Symposium (pp. 15-17).

Zimmermann, F., Eling, C.and Kuhlmann, H. 2017. *"Empirical assessment of obstruction adaptive elevation masks to mitigate site-dependent effects*". GPS Solutions, 21(4), 1695-1706.