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Performance Analysis of Internet-based DGPS and Commercial Satellite-based Augmentation System: A Case Study in Peninsular Malaysia

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***Abstract* — Global Navigation Satellite Systems (GNSS) has become an essential component in modern times for positioning, navigation, and timing. A fast-growing economic region in Malaysia required a GNSS-based augmentation positioning and navigation service. To improve navigation solution, several augmentation techniques exist, such as a differential Global Positioning System (DGPS) assisted by reference station, or augmentation service provided by commercial communication satellite. The DGPS correction is applied through a real-time communication medium and can be received at the user side by several communication methods including internet-based, and this method is favourable for land and near-coast areas. This case study aims to investigate the reliability of internet-based DGPS and SBAS along the Peninsular Malaysia. A test was conducted and data were collected over 15 hours at a rate of 1 Hz from the available GNSS satellite using a geodetic-grade receiver mounted on a moving vehicle. The obtained results showed that DGPS and SBAS perform better than the navigation solution with an accuracy of 1.536 m and 0.955 m respectively, compared to the navigation solution with an accuracy of 3.159 m. The limitations of both augmentation techniques were also analysed and discussed in this study.**

Keywords—PNT, GNSS, Internet based DGPS, SBAS, Augmentation

I. INTRODUCTION

Global Navigation Satellite Systems (GNSS) has played a pivotal role in providing Positioning, Navigation, and Timing (PNT) support for a wide range of activities, such as navigation [1], e-hailing to vessel tracking, surveying, deformation monitoring [2] and meteorology [3]. The public has grown dependent on this technology, particularly for navigation and location-based services. As of 2017, GPS had contributed approximately 215 billion USD in economic benefits [4], with its contribution increasing consistently over time. Among the available GNSS constellations, GPS is the earliest constellation to achieve fully operational and is still the most widely used GNSS in the world. GPS has been able to support 3D navigation with accuracy from 5 m to 10 m [5]. Accuracy can be improved through augmentation techniques, like DGPS or Satellite-Based Augmentation System (SBAS).

The accuracy of DGPS ranges from meter to sub meter. Various techniques can be utilised to model the DGPS correction [6], all of which necessitate reliable reference stations. These ground reference stations are normally Continuously Operating Reference Stations (CORS) that has been established on stable structure at strategic and known locations to continuously collects GPS/GNSS measurements. DGPS corrections are generally broadcast in real time through radio signals from a radio beacon, but now also could be sent over the Internet due to advancements in telecommunications technology.

In the meantime, SBAS offers comparable accuracy to DGPS but transmits corrections to the user through satellite communication. Data collected from CORS is transmitted to a central control centre for modelling Once corrected, the data is transmitted to a satellite and then delivered to the user, provided that the user has a compatible receiver and being subscribed to the SBAS services. Several SBAS

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services available such as the US Wide Area Augmentation System (WAAS), Multi-functional Satellite Augmentation System (MSAS), European Geostationary Navigation Overlay Service (EGNOS), System for Differential Corrections and Monitoring (SDCM), and GPS-aided GEO augmented navigation (GAGAN) [7, 8]. Most SBAS services are region based and are developed by local agencies, whereas commercial SBAS services such as OmniSTAR, Starfire, and Veripos are available globally [9].

This case study aims to investigate the reliability of internet-based DGPS and SBAS in Peninsular Malaysia. Internet-based DGPS correction was generated using a reference station from the National Research & Development CORS Network (NRC-net), while SBAS correction was obtained through OmniSTAR, a commercial SBAS service. More than 15 hours of GPS data has been collected at a frequency of 1 Hz.

This paper consists of six sections. Section I provides a brief overview of the study and introduces the DGPS, SBAS, and GNSS/GPS. The data collected for this study is outlined in Section II. Section III discusses data processing, while Section IV presents the findings and analysis. Section V elaborates on the constraints of internet-based DGPS and SBAS in Malaysia. The study's conclusions are outlined in Section VI along with additional recommendations.

II. DATA COLLECTION

A two-day data collection campaign was executed from 1st to 2nd August 2023. Figure 1 showed the data collection route of this campaign.

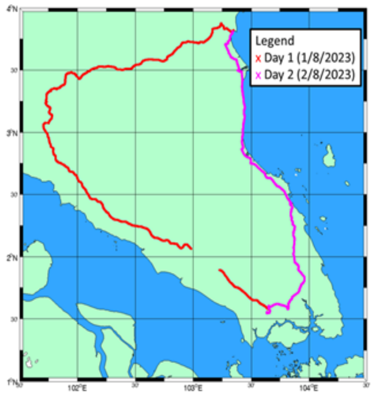

Fig. 1. Data collection route over the 2 days.

Over two days, a total of 55,128 seconds (15.313 hours) of data were collected; whereby 28,105 seconds (7.807 hours) of data were collected on the first day, while 27,023 seconds (7.506 hours) on the second day. However, there were a few gaps on the first day because of some technical difficulties with the instrument setup.

Two geodetic-grade antennas and three receivers were used in this data collection campaign. The first antenna is a 3200LR12 OmniSTAR connected to a Trimble 4700 receiver, dedicated to collect commercial SBAS augmented position. The second antenna is a Hemisphere A31 antenna connected to two receivers, a Hemisphere R330 GNSS receiver and a custom-made Novatel receiver. The Hemisphere R330 is used to process the DGPS correction received from an internet-connected computer, while the Novatel receiver collects raw measurement data for post-processing. SBAS and DGPS positions are provided in National Marine Electronics Association (NMEA) format 0183, which is widely used in GPS positioning.

Figure 2 showed the schematic set-up of the instruments, while Figure 3 depicted the positioning of the antennas on the moving vehicle. An offset of 1.5 metres exists between the 3200LR12 OmniSTAR and Hemisphere A31 due to the instrument setup. This offset was taken into account during data analysis.

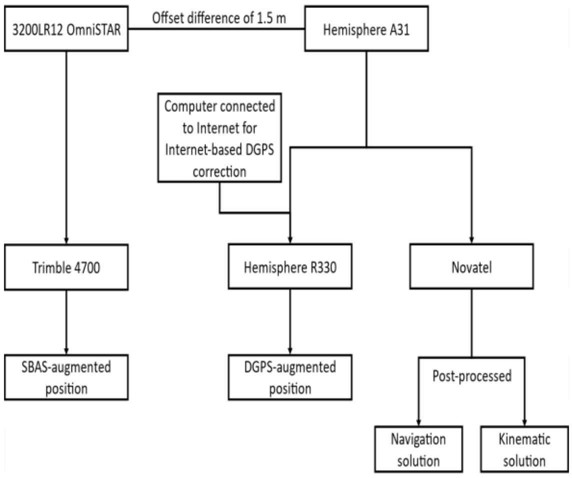

Fig. 2. Schematic drawing of the instrument set-up.

Fig. 3. Antennas mounted on moving vehicle.

III. DATA PROCESSING WORK

Raw data has been processed using RTKLib ver 2.4.3 to compute the position using single point positioning and kinematic technique. Single point positioning is also often known as a navigation solution that uses code pseudorange measurement and is expected to have an accuracy of 5 m to 10 m. Kinematic positioning, on the other hand, uses higher accuracy phase measurement, and the expected accuracy is at centimeter level when the ambiguity can be fixed, or decimetre accuracy when the ambiguity can only be estimated to a floating number [9]. Table I shows the settings in RTKLib that were used to process navigation and kinematic solution.

Table I. Settings in RTKLib used to process raw data.

Settings	Navigation solution	Kinematic solution
Positioning Mode	Single	Kinematic
Frequencies	Not applicable	L1+L2 Combined
Elevation Mask (°)	15	15
Ionosphere Correction	OFF	Iono-Free LC
Troposphere Correction	OFF	Estimate ZTD
Satellite Ephemeris/Clock	Broadcast	Broadcast
Integer Ambiguity Resolution	Not applicable	Continuous
Time Format	hh:mm:ss UTC	hh:mm:ss UTC

The time format for the result was Coordinated Universal Time (UTC), as is the output for DGPS and SBAS in NMEA-0183. Before comparing accuracy, the time between different solutions must be synced.

All types of processed solutions, including DGPS, SBAS, Navigation and Kinematic were initially in World Geodetic System 1984 (WGS84) coordinates. Navigation focuses more on the 2D planar position thus the solutions are all projected into Universal Transverse Mercator (UTM) zone 48N for the purpose of analysis. Apart from that, the kinematic solution is assumed to provide the position with the highest accuracy as it uses a more precise measurement. Thus, the kinematic solution is chosen as the reference when comparing the accuracy of the various solutions.

The 2D error (ε_{2D}) of each solution can be calculated using Eq. (1).

$$\varepsilon_{2D} = \sqrt{(N_{kinematic} - N_{solution})^2 + (E_{kinematic} - E_{solution})^2} \tag{1}$$

, where N and E represents northing and easting in meter respectively, and subscript kinematic and solution represents kinematic solution and the compared solution (DGPS, SBAS, navigation).

Meanwhile, the root-mean-squared error (RMSE) and standard deviation are used to quantify the accuracy and precision of the solution, respectively. The formula for RMSE and standard deviation are showed in Eq. (2) and Eq. (3) respectively.

$$RMSE = \sqrt{\frac{1}{N_i}\sum_{n=1}^{N_i}(\varepsilon_{2D})^2} \tag{2}$$

$$Standard\ deviation = \sqrt{\frac{1}{N_i - 1}\sum_{n=1}^{N_i}(\varepsilon_{2D} - \overline{\varepsilon_{2D}})^2} \tag{3}$$

, where N_i represents number of solutions, and $\overline{\varepsilon_{2D}}$ denotes the mean of 2D error.

The large distance between reference stations and data collection leads to reduce the reliability of kinematic solutions in resolving ambiguity to the integer value. This study utilised solely a float kinematic solution to determine the accuracy and precision of the solution. In addition, the solutions from DGPS and SBAS are mixed with various accuracy, but only DGPS solution and OmniSTAR VBS are chosen for this case study, as they provide the most accurate solutions.

IV. RESULT AND ANALYSIS

Figure 4 showed the results of 2D error for each solution over time. The results showed that SBAS has the lowest error, followed by DGPS and navigation solutions.

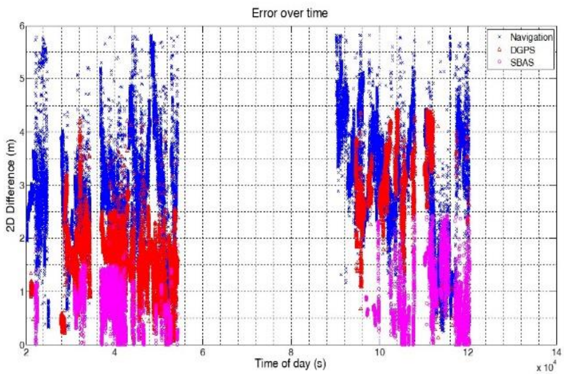

Fig. 4. 2D error for each solution over time.

Table II outlines the performance of these solutions, and it showed that DGPS and SBAS provide a better accuracy and precision compared to the navigation solution. OmniSTAR SBAS performs better than DGPS in both accuracy and precision. Improvement of DGPS and SBAS against navigation solution are showed in Table III.

Table II. Accuracy and precision assessment of different solutions.

	Navigation	DGPS	SBAS
RMSE (m)	3.159	1.536	0.955
Standard Deviation (m)	1.056	0.626	0.504
Min (m)	0.238	0.016	0.000
Max (m)	5.844	3.257	2.317
Mean (m)	2.978	1.403	0.682

Table III. Improvement of DGPS and SBAS compared against navigation solution.

Improvement	DGPS	SBAS
Accuracy (%)	51.37	69.77
Precision (%)	40.72	52.27

The performance of DGPS is affected by the distance to the reference station whereby the longer the distance, the correlation of errors are weaker, thus the weaker the performance. In this study, the average distance to the reference station is 144.42 km. An experiment performed by Monteiro *et al.* [10] in the United States shows that the accuracy degradation is 0.22 m for each 100 km between the reference station and the point of interest. It is expected to have an average accuracy degradation of 0.31 m for this case study.

In addition to accuracy and precision, the availability of corrections is crucial for navigation. DGPS has 34,616 seconds of non-navigation solution, whereas OmniSTAR SBAS has 35,096 seconds of data. DGPS has a 62.79%, whereas OmniSTAR SBAS has a 63.66% availability of navigation solutions. This showed that OmniSTAR SBAS slightly better correction availability compared to DGPS.

V. DISCUSSION

Based on the analysis of the results, it was determined that both DGPS and OmniSTAR SBAS perform better than standard navigation solutions, with OmniSTAR SBAS outperforming DGPS. In the following section, the limitations of DGPS and OmniSTAR SBAS are discussed in greater detail.

DGPS exhibits improved performance when in close proximity to the reference station. The average distance to the reference station in this case study is 144.42 km, which is considered a significant distance. The switching of reference stations was done manually, which did not guarantee the use of the nearest reference station for DGPS correction. Thus, an intelligent reference station selection algorithm should be implemented to improve the accuracy of DGPS correction. Furthermore, the availability of reference stations for DGPS in the NRC-net coverage is limited. Densifying the CORS available will open up more options for future users, or integrating it with other available CORS networks such the Malaysia Real-time Kinematic Network (MyRTKnet), managed by the Department of Survey and Mapping Malaysia (JUPEM).

OmniSTAR SBAS is a commercial service that requires payment for use. Dedicated receivers are necessary to receive signals from the OmniSTAR satellites. This limits the application to public users who prioritise cost-effectiveness over accuracy and precision.

However, both corrections are constrained by communication. Internet-based DGPS is constrained by its reliance on internet connectivity. This limitation is more significant for marine navigation, where internet connectivity relies on costly communication satellite services, compared to land areas that can be easily covered by mobile communications. Apart from that, OmniSTAR SBAS is limited by satellite availability, whereby it will experience short outages when the satellite is out of track. Figure 5 showed a case of OmniSTAR SBAS outage during data collection.

Fig. 5. Sample of OmniSTAR satellite outage.

VI. CONCLUSION

A study on Internet-based DGPS and SBAS has shown that both methods outperform the navigation solution in terms of accuracy and precision. DGPS has an accuracy of 1.536 m, an improvement of 51.37% over the navigation solution while SBAS has an accuracy of 0.955 m, an improvement of 69.77% over the navigation solution. SBAS performs slightly better than DGPS.

The limitations of both augmentation techniques were also discussed. DGPS is mainly limited by the reference station, whereby an intelligent reference station selection algorithm should be applied to improve the performance of DGPS. Furthermore, increasing the distance between reference stations for correction would enhance the performance of DGPS. On the other hand, SBAS shows limited application as it requires dedicated receivers and extra cost to subscribe to the services. Both techniques are also limited by communication methods, whereby DGPS is limited by internet accessibility while SBAS is limited to satellite tracking. However, as this is a case study, the results may be limited temporally and regionally. Additional research and data collection are needed to provide deeper insights on the performance of DGPS and SBAS in the region.

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