FREE BROADCAST DGPS SERVICE IN MARINE: HOW GOOD IS IT?

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Abstract

Differential GPS (DGPS) has been used widely in many types of application including for marine navigation and hydrographic surveying. Most of the recent DGPS receiver development applies the use of code and carrier phase on single frequency L1 C/A code receiver for submetre horizontal accuracy. Differential Global Navigation Satellite System (DGNSS) radio beacon is a system that uses the concept of DGPS based on pseudorange measurements. This system provides free DGPS corrections using the commercial reference station with proper receivers. The availability of reference station that operates 24 hours a day means that the users are no longer required to set up their own reference station. This study is intended to evaluate the performance of DGNSS radio beacon, not only for horizontal positioning but also for data availability and reliability at the remote receiver. For this purpose, static and dynamic test have been carried out on the DGPS corrections received from DGNSS radio beacon. Both of the tests make use of the National Marine Electronic Associations 0183 (NMEA 0183) data format generate by remote receiver to examine the DGPS broadcast signal. The results show how the distance separation (static test) effects the age of DGPS correction, horizontal dilution of precision (HDOP), numbers of satellite use and also the signal strength recorded at remote receiver. Meanwhile, the tracking method (dynamic test) differentiates the automatic and manual tracking results. This is to estimate the most suitable method to be used for marine navigation and hydrographic surveys.

Keywords: *DGPS, marine navigation, hydrographic survey*

1.0 INTRODUCTION

Differential Global Navigation Satellite System (DGNSS) radio beacon is a system designed as an aid to safety for marine navigation. In comparison to a terrestrial navigation or any other direction-finding system, DGNSS radio beacon systems used Global Positioning System (GPS) satellite (some used Global Navigation Satellite System (GLONASS)) to position a vessel at sea. By using real time Differential GPS (DGPS) method, users can get better result rather than with a single receiver. To receive corrections from a DGNSS radio beacon, users are required to encompass a GPS receiver that is capable to track the signal transmits by the system.

2.0 DGNSS RADIO BEACON SYSTEM

Differential Global Navigation Satellite System (DGNSS) radio beacon has been recognized in most country as an aid to safety for marine navigation. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) has listed all DGNSS stations that are officially operated around the world. The authorized frequency for DGNSS radio beacon is between 283.5 kHz to 325 kHz. In this way, users are able to receive DGPS correction through Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format (IALA, 2001). Figure 1 shows a DGNSS radio beacon system. A typical DGNSS station consists of the following components:

a) Reference Station
   Generate the DGPS correction.
b) Control Station
   Used for fault detection and correction.
c) Integrity Monitor
   Verify the correctness of the corrections generated by the Reference Station.
d) Transmitter
   Broadcast the DGPS corrections generated by the Reference Station to users.
e) Control Monitor
   Monitor the status of the DGNSS system.

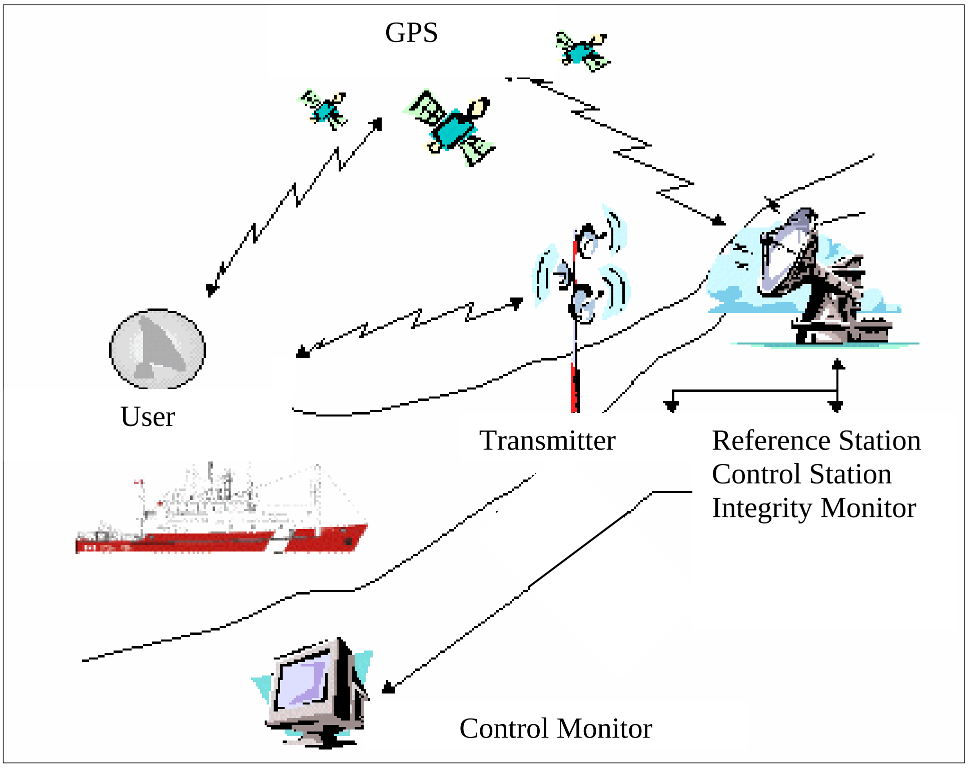

Figure 1: DGNSS radio beacon system

Each DGNSS radio beacon system has its frequency and also an identification (ID) station number. This is to make sure that users know exactly which signal is been recording. To receive a signal from DGNSS radio beacon, user needs to have a Minimum Shift Keying (MSK) radio beacon receiver with antenna and a minimum of L1 C/A code GPS receiver with its antenna. Nowadays, most of the receiver manufacturers have developed a combined MSK radio beacon and GPS receiver with a combined MSK and GPS antenna. MSK receiver will demodulate the signal from DGNSS radio beacon to receive the differential correction. The differential correction will be applied to GPS position in order to get position in DGPS mode.

3.0 STATIC TEST FOR DGNSS RADIO BEACON

Essentially, an appropriate technique to determine the accuracy of real time DGPS system is to test the position solution compare to a known station. Two tests have been carried out using two separate ranges from DGNSS radio beacon. Both of the tests were conducted using Trimble DSM212H receiver on a known point inside Universiti Teknologi Malaysia (UTM) main campus, which is BC10. Note that BC10 has been set up using a post-processing static GPS survey through the global International GPS Service (IGS) station and also the Malaysian Active GPS System (MASS) station run by the Department of Survey and Mapping Malaysia (DSMM). The observations were recorded from Pulau Satumu, Singapore DGNSS station (46 kilometres) and from Kuantan DGNSS station (250 kilometres) for about 24 hours for each station (Figure 2). Note that both of the observations were recorded independently on two different days using BC10 as a known station. The observations are in National Marine Electronics Association 0183 (NMEA 0183) format.

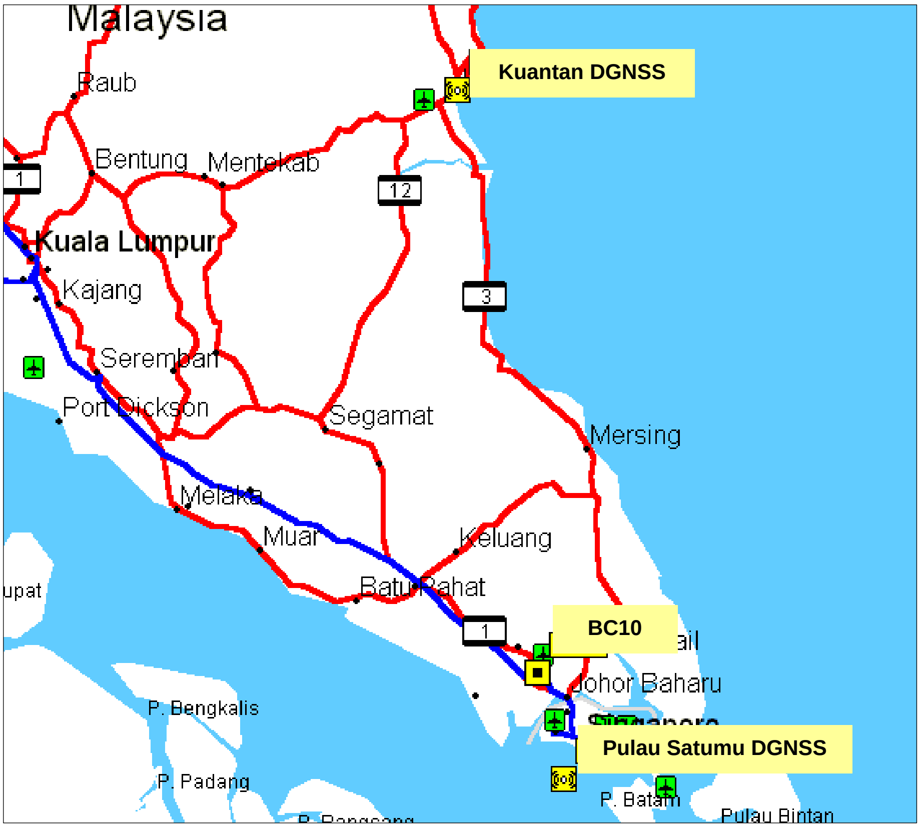

Figure 2: Map showing DGNSS radio beacon station at Kuantan and Pulau Satumu from BC10

Besides using difference distance, the tests will also evaluate some other factors such as the effect of the age of DGPS correction and the percentage of the DGPS fix recorded. The reason for the observations being recorded for 24 hours is to determine the best time for the DGNSS radio beacon for the transmission of the differential corrections. This is because the use of medium frequency (MF) radio signal by the station is easy to be affected by skywave and groundwave propagation. However, the study of the skywave and groundwave propagation is not intended to be enlightened here since it is beyond the span of this research.

4.0 DYNAMIC TEST FOR DGNSS RADIO BEACON

The focus of this test is to investigate the tracking methods of DGNSS radio beacon mostly used by DGPS receivers. Two types of tracking methods were tested, namely automatic and manual. The first is the automatic method. Using this technique, DGPS receiver will automatically receive the strongest DGNSS radio beacon signal. Meanwhile, the latter technique will only select a signal from a specified DGNSS radio beacon station. Both of the position solution techniques were compared to a Wide Area DGPS (WADGPS) services to study the position differences. In the test, three receivers were used, whereby two receivers received the DGNSS radio beacon signal and one receiver received the WADGPS signal. The analysis will only take into consideration if the three receivers have the equal time fixing. In this case, the Universal Time Coordinated (UTC) from the NMEA 0183 messages was used.

5.0 RESULTS FOR STATIC TEST

DGNSS NMEA Analysis Program (DNAP), a computer program developed at UTM, was used to analyze both the static and dynamic test since huge amount of data are involved in this test and there is still no specified software to study the NMEA 0183 messages.

To evaluate a positioning system, it is important to draw attention to the availability and the reliability of the system. In this research, the availability can be described as the available data, which can be recorded in a certain time. This refers to the numbers of fix, which are recorded via differential mode (DGPS). Besides the DGPS fix, there are two other types of fix, which is the stand-alone fix and fix which are not valid. Stand-alone fix is a position solution without differential correction from reference station. Meanwhile, fix that are not valid occurs when there is no position solution from the receiver. The receiver also has been configured to reject the fix which contain the age of differential correction more than 30 seconds and also if the satellite elevation reached more that 15 degrees (the value set is according to the best value recommended by the receiver manufacturer).

To detect outliers and any gross errors, a 3 sigma (3σ) statistical test has been used before all data are analyzed. The purpose for the test is to remove outliers from the data. To carry out this test, standard deviation (σ) for the observation must be compute using the following equation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \qquad [6.1]$$

where,

$\bar{x}$ = mean of observation
x_i = observation
n = numbers of observation

Besides the standard deviation, an average value for the observation was also calculated. If the discrepancy between the average value and an observation recorded exceeds 3σ, then the specific observation will be rejected. The tests are carried out for every observation before proceeding with the availability and reliability issues.

Table 1 shows the availability for the static test using 46 kilometres and 250 kilometres reference station in 24 hours time period. For a 24 hours observation with one-second interval, there should be 86,400 fixes. Therefore, availability in Table 1 can be expressed by:

$$\textit{Availability}\ (24\ \text{hours}) = \frac{\text{Fix with DGPS}}{86{,}400} \times 100 \qquad [6.2]$$

From Table 1, it shows that for a maximum coverage of 250 kilometres (most of the DGNSS radio beacon coverage is between 200 to 250 kilometres), the available DGPS fix for one day is 93.59 percent. At medium distance (46 kilometres), at least 99 percent of recorded data were carried out by DGPS mode.

Table 1: Percentage of data availability at different distance

Types of fix / Distance	No. of fix recorded	Fix with DGPS	Stand-alone fix	Not valid fix	*Availability*
46 km	85,947	85,917	14	16	99.40 %
250 km	85,877	80,866	4,797	214	93.59 %

The reliability for this test can best be described as how reliable the data was or can be expressed as: "can we believe the DGPS fix". The reliability can be calculated by:

$$\textit{Reliability}\text{ (24 hours)} = \frac{\text{DGPS fix (pass } 3\sigma \text{ test)}}{86{,}400} \times 100 \qquad [6.3]$$

Table 2 shows the number of fix, which passed 3σ tests. It shows that the reliability for the 46 kilometres distance is 99.42 percent and 92.75 percent for 250 kilometres distance. The result shows the about value compared to the availability outcome. Both of the availability and reliability results agreed that at least 99 percent from all the data for 46 kilometres are recorded using DGPS mode and can be truly trusted.

Table 2: Percentage of data reliability at different distance

Types of fix / Distance	No. DGPS fix	Passed	Failed	*Reliability*
46 km	85,917	85,903	14	99.42 %
250 km	80,866	80,136	730	92.75 %

From the 46 kilometres and 250 kilometres distance observation, the coordinate differences, the age of DGPS correction and also the signal strength were analyzed. Figure 3 and 4 represent two-dimensional coordinate dispersion for 46 kilometres and 250 kilometres distance (24 hours observation). The 46 kilometres distance observation produce horizontal accuracy of 0.55 metres while the latter observation offer 1.86 horizontal accuracy. At 95 percent confidence level (multiplied by 2.45 for two dimensional accuracy, Hofmann, et al., 2001), the accuracy is 1.35 metres (46 kilometres) and 4.58 metres (250 kilometres). Figure 5 and 6 show the age of DGPS correction for both of the observation. The 250 kilometres observation produces more high age of DGPS correction rather than the 46 kilometres distance. Besides the age of DGPS correction, numbers of satellite used by 250 kilometres distance observation also degrade because of high distance separation (Figures 7 and 8). The increase of horizontal dilution of precision (HDOP) value explains that a longer distance observation has poor horizontal satellite geometry.

Signal strength recorded during both of the observations also describes the effect of longer distance separation. Figure 9 and 10 shows the signal strength during the observations and Table 3 summarizes the value recorded in decibel microVolt per meter (dB μV/m). In Europe, the signal strength recorded must be at least 20 dB μV/m and above or as published by the local authority (Grant, 2002). This is to make sure that the signal is strong enough to prevent from any interfering. At 250 kilometres (Figure 10), the signal was unstable at the middle of observation (11:00 to 24:00 UTC), which is approximately from 6.00 pm to 8.00 am local time (late evening to early morning). In the meantime, the beginning and the last signals show a consistent variation around 20 dB μV/m.

Table 3: Minimum, maximum and average value of signal strength recorded

Value (dB μV/m) / Observations	Minimum	Maximum	Average
At 46 km	1.0	70.5	48.4
At 250 km	0	56.0	27.0

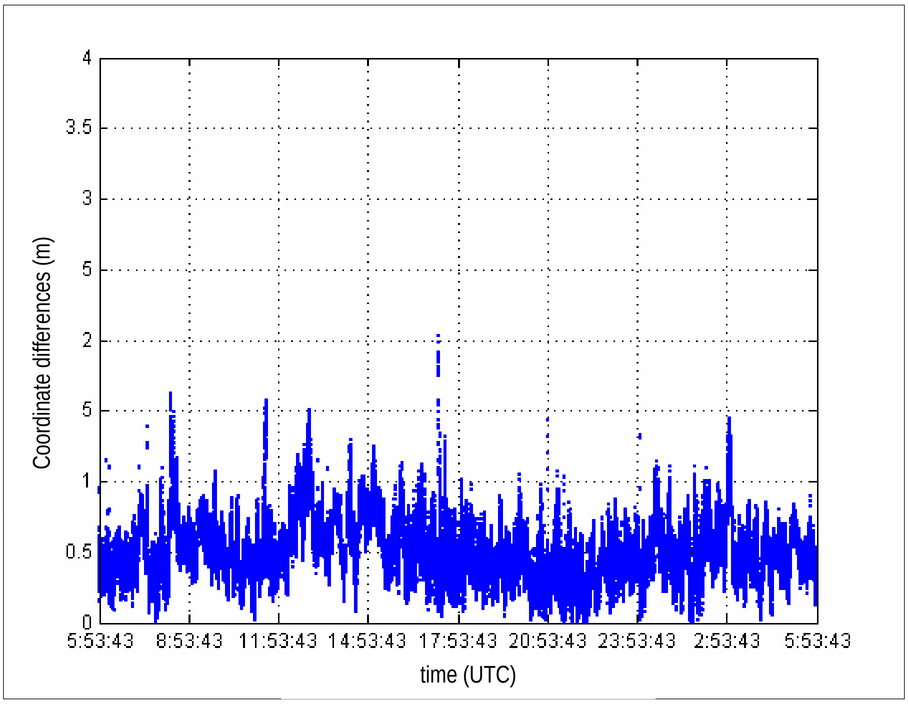

Figure 3: Coordinate differences at 46 kilometres distance

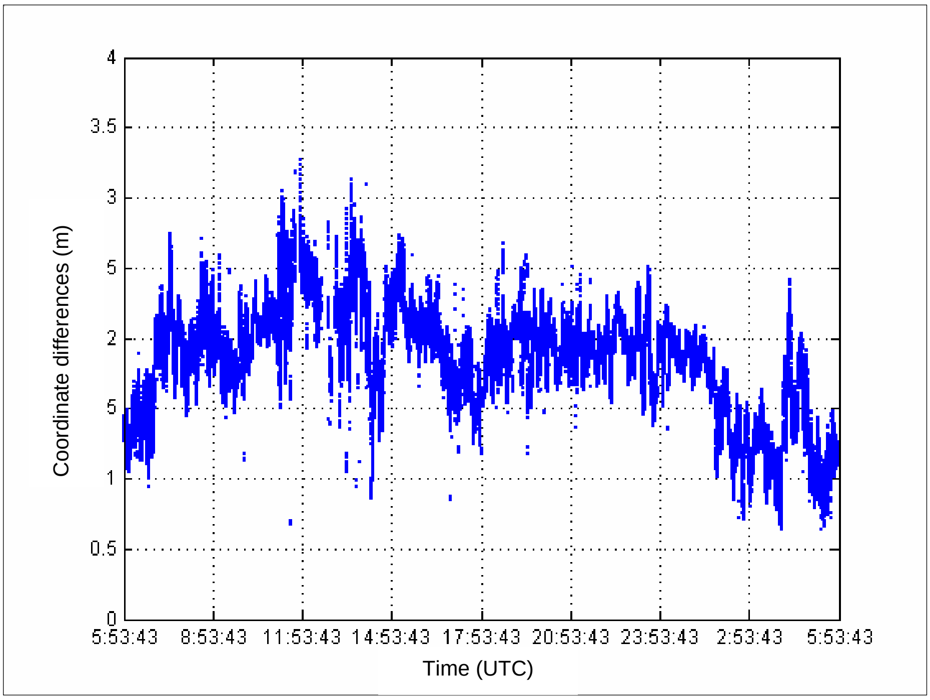

Figure 4: Coordinate differences at 250 kilometres distance

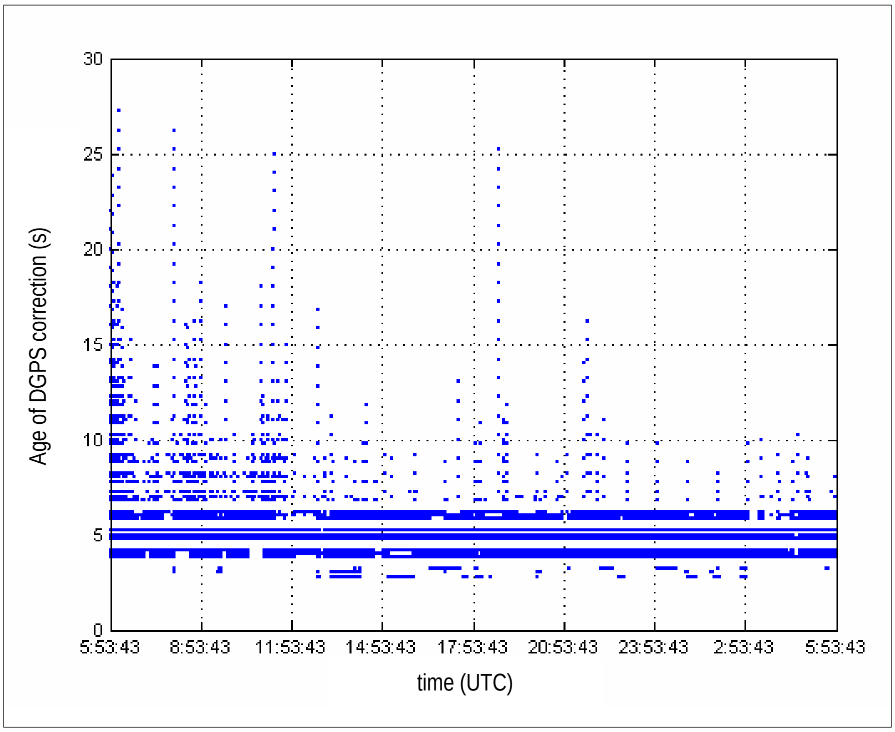

Figure 5: Age of DGPS correction at 46 kilometres distance

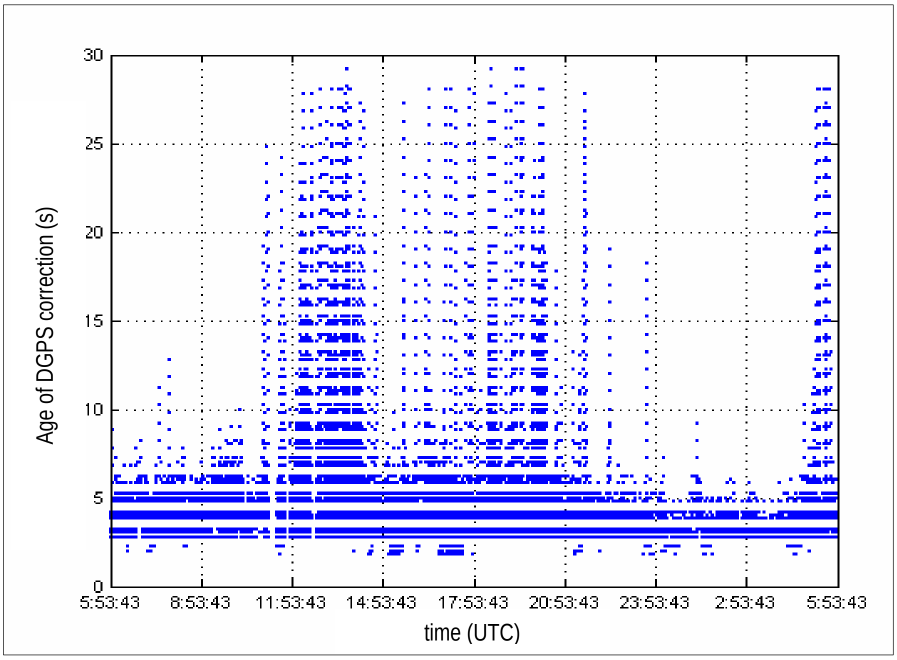

Figure 6: Age of DGPS correction at 250 kilometres distance

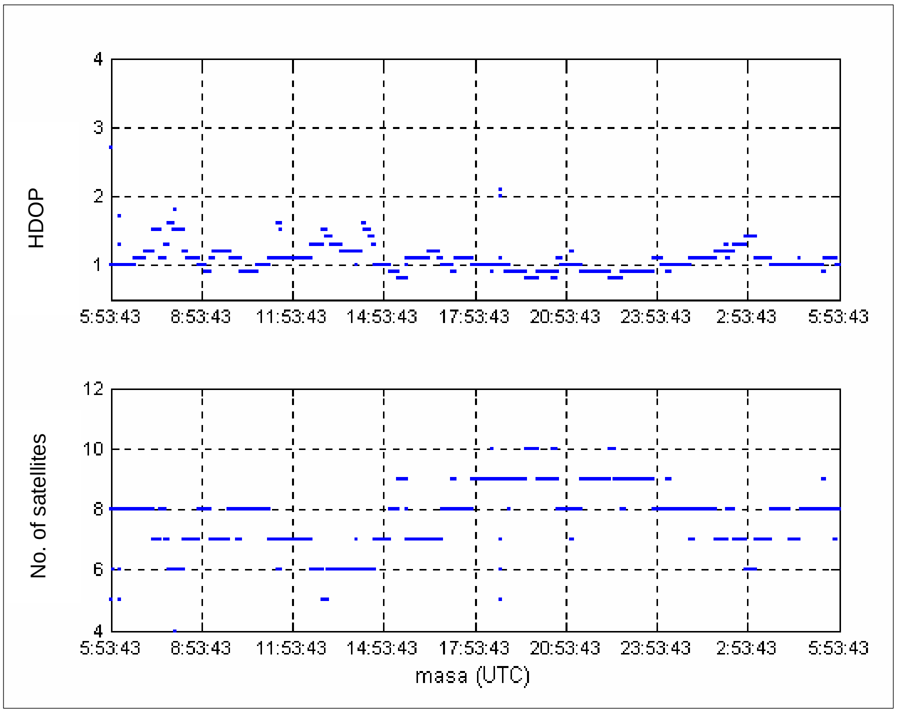

Figure 7: HDOP value and numbers of satellite used at 46 kilometres

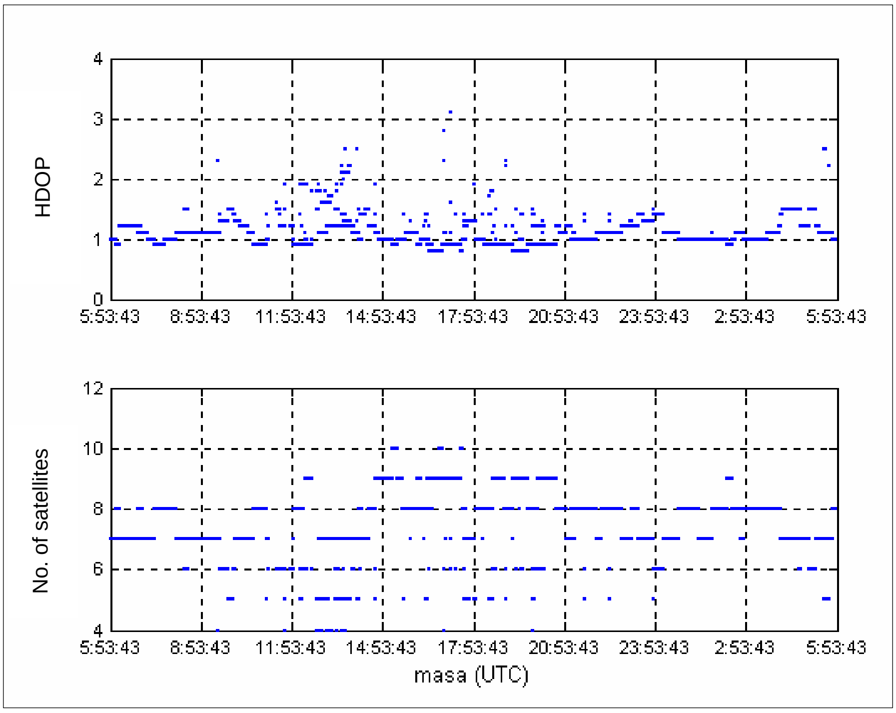

Figure 8: HDOP value and numbers of satellite used at 250 kilometres

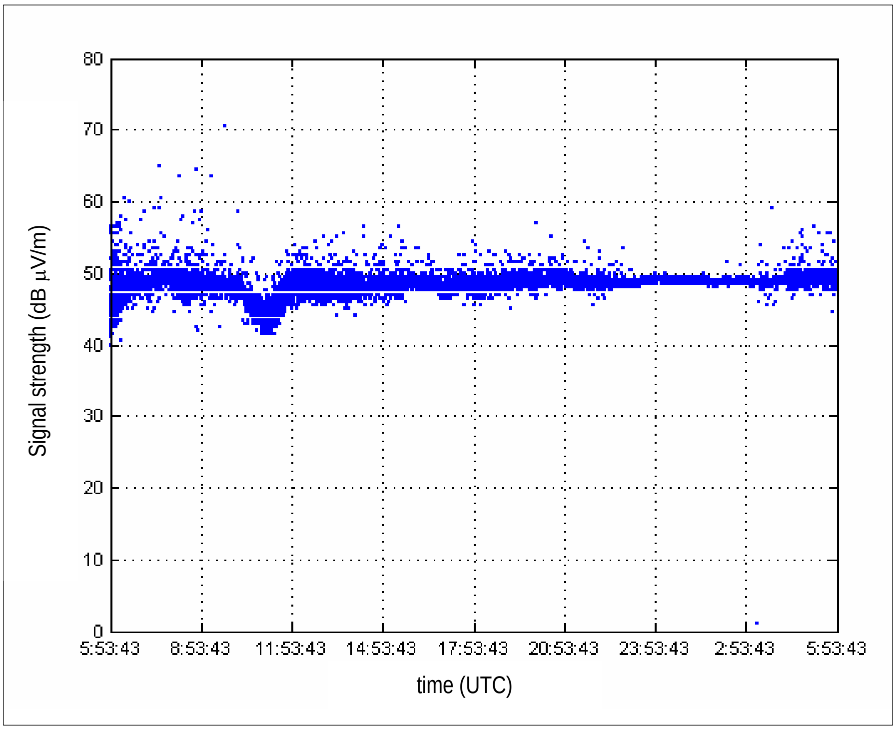

Figure 9: Signal strength (in decibel microVolt per meter) at 46 kilometres distance

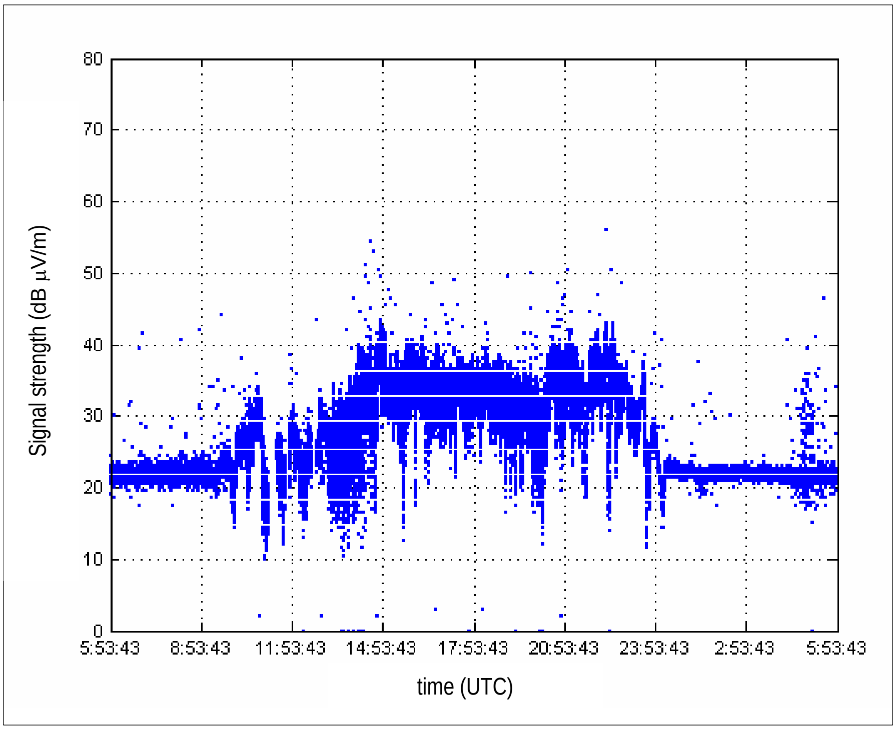

Figure 10: Signal strength (in decibel mikroVolt per meter) at 250 kilometres distance

6.0 RESULTS FOR DYNAMIC TEST

Instead of coordinate differences, the term 'antenna separation' will be used in this dynamic analysis due to the antenna movement during the test. A better result is illustrated by a small value of antenna separation. Table 4 and 5 summarize antenna separation value between the two methods. The mean and range value for antenna separation have been compute at every 50 kilometres to more than 200 kilometres distance. It is prove that the value for Table 5 (manual tracking method) is better than the automatic method. However, the change of mean value at different distance is somehow insignificant for both of the method. For more information, Figure 11 and 12 graphically shows the antenna separation value, age of DGPS correction, signal strength and also station identification during the test.

Table 4: Mean and range value of antenna separation at different distance (automatic tracking methods)

	Distance from station				
	0-50 km	**50-100 km**	**100-150 km**	**150-200 km**	**>200km**
Mean of antenna separation (m)	1.85	1.91	1.66	1.89	2.49
Range of antenna separation m)	0.01 - 3.98	0.25 - 3.96	0.40 - 3.14	0.56 - 4.40	0.34 - 15.68

Table 5: Mean and range value of antenna separation at different distance (manual tracking methods)

	Distance from station				
	0-50 km	**50-100 km**	**100-150 km**	**150-200 km**	**>200km**
Mean of antenna separation (m)	0.63	0.91	0.96	0.96	0.83
Range of antenna separation m)	0 - 1.77	0 - 1.81	0.01 - 1.81	0 - 2.18	0 - 4.17

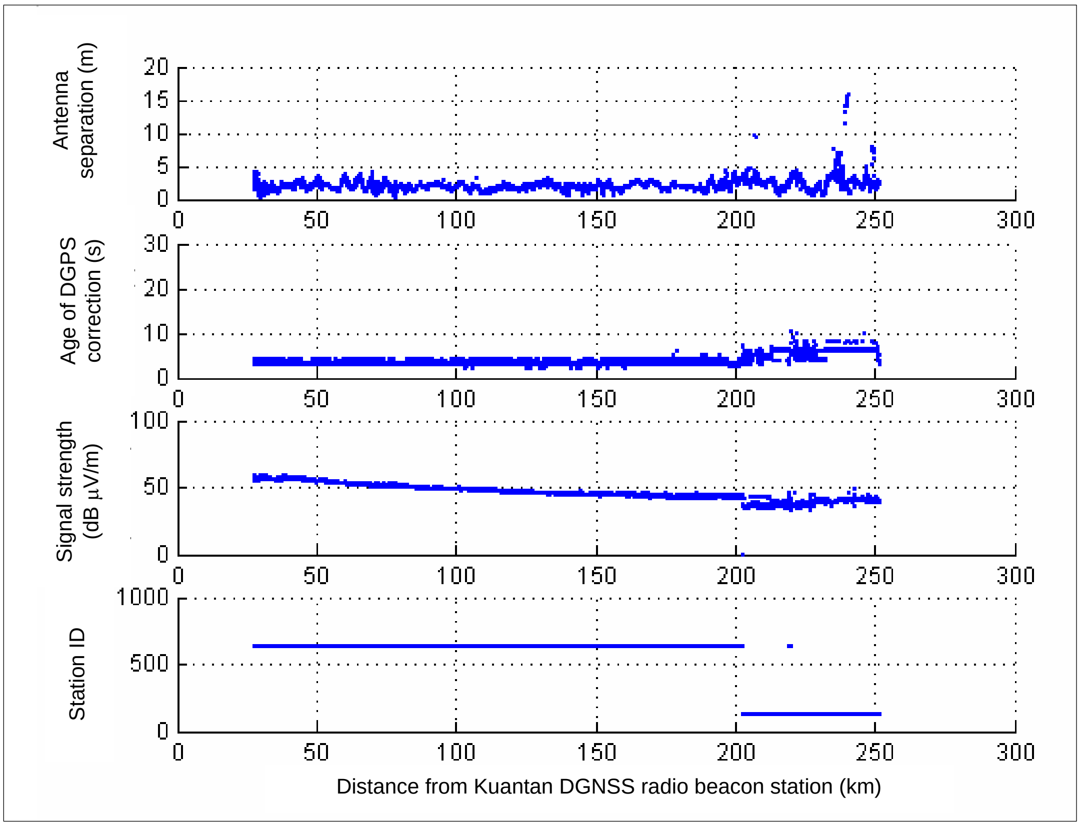

Figure 11: Result for automatic tracking method (dynamic test)

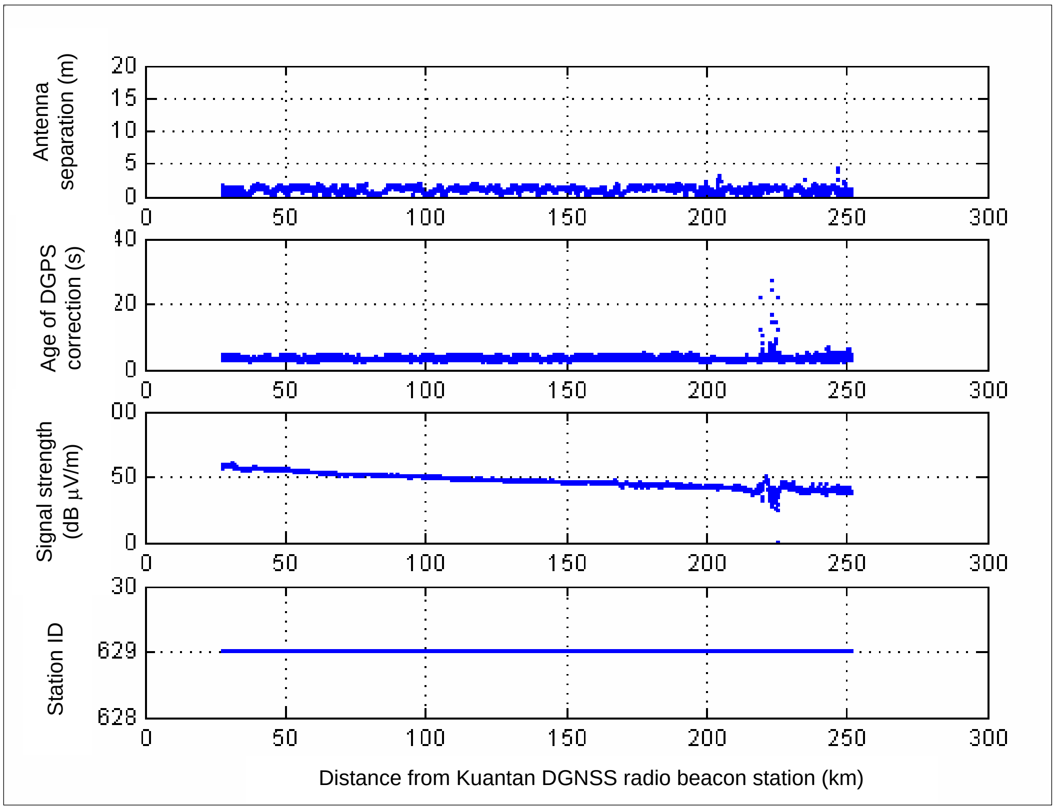

Figure 12: Result for manual tracking method (dynamic test)

7.0 CONCLUSION

Distance separations between the reference station and user are the main factors, which degrades the accuracy. Due to the increase distance, the reference station and user will not experienced the same errors (ionosphere, ephemeris, satellite clock) anymore. This also will increase the age of the DGPS correction, which will lead to a latency issue. Meanwhile, the worst signal strength recorded has been identified at 6.00 pm to 8.00 am local time (late evening to early morning). However, the static test has been carried out on the ground and not at sea. For further study, the authors suggest that a proper static test at sea can be made to describe the true marine signal.

For the dynamic test, the result from the manual tracking method is much better than the automatic method. To use the manual tracking method, users should recognize some information about the DGNSS radio beacon station. This includes the frequency transmitted by the station, station identification number and also the status of the station (operate or not). This is to make sure that the right signal is been received from the right station.

Further investigation on the availability and the reliability for the system is needed due to the variety of individual, which currently used it. The primary users may be the marine navigators (marine navigation) and the hydrographic surveyors (positioning hydrographic works). The system will provide a lot of benefits for these users since the service is a 24 hours free broadcast signal.

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