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ORIGINAL ARTICLE

Outdoor Localisation for Navigation Tracking using Differential Global Positioning System Estimation (DGPS) : Positioning Errors Analysis

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ABSTRACT – Global Positioning System (GPS) is a very popular outdoor positioning system. Due to the satellites' errors signal, the Global Positioning System (GPS) receivers determine the accuracy of a current location with about 100 meters in latitude and 156 meters in longitude. In this few years, the technology on autonomous vehicles is rising. Autonomous vehicles need to navigate with high positioning accuracy for preventing any potential danger to road user. So in this paper, Differential Global Positioning System (DGPS) experiment will be introduced for improve the positioning accuracy. Differential Global Positioning System (DGPS) operations compose of Reference Station and Rover Station. Both of the station will use the GPS receiver for receiving the positioning data from GPS satellites and the positioning data collected from Reference Station will be used to calculate the positioning errors and the errors correction will then be transferred to Rover Station to improve the positioning accuracy. The results obtained will be discussed based on the average and range of errors in both latitude and longitude, number of satellites detected, Horizontal Dilution of Precision (HDOP), Vertical Dilution of Precision (VDOP) and the improvement on Differential Global Positioning System (DGPS) at the same time in different day. In four days' results, it can be seen that the number of satellites detected will be affected by the Horizontal Dilution of Precision (HDOP) and Vertical Dilution of Precision (VDOP) which cause the positioning errors in latitude and longtitude. The average of positioning errors range between -4.165m and 2.925m in latitude and -0.618m and 1.998m in longitude.

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KEYWORDS
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DGPS
Position Domain
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Introduction

GPS is a satellite-based radio navigation system that has been operated by United Air Force and owned by the U.S government. It is also a global navigation satellite system that transmit positioning information to a GPS receiver when there is unobstructed line of sight to four or more GPS satellites. Obstacles such as building blocks and mountain cause the GPS signals weaker [1]. In worst case, all signals may be blocked making position calculation impossible. In general, the high the number of visible satellites, the better the accuracy.

GPS is popular among the public users for navigation purposes. It has an overall accuracy of approximately 25 meters suitable for most navigational applications, based upon governmental selective availability [2]. Besides, GPS is also used for applications that related to recently developed autonomous devices. GPS is also used by these devices as a primary source for navigation purposes. Furthermore, the autonomous ground vehicles require a high level of accuracy to be able to follow a defined path and do not overpass a defined area, but GPS has only limited precision and accuracy. In addition, the flying objects require the same accuracy in vertical domain [3-4].

The dilution of precision (DOP) also contributes to the accuracy of the GPS calculations but not in direct manner. Physically, DOP describes the geometric strength of the visible satellites' configuration on the GPS accuracy. Ideally, the visible satellites should be located at wide angles relative to each other. The geometry of such configuration is said to be strong and cause low DOP values. Conversely, if the visible satellites have small angular separation, the satellites' configuration has weak geometry and cause high DOP values.

The most useful DOP values for GPS-guided vehicles are the HDOP and VDOP as these values are used in calculations for estimating the Circular and Height Error Probable (CEP & HEP). HDOP is used for describing how a pseudorange affects the horizontal position on latitude, x and longitude, y. VDOP is used for describing how a pseudorange affects the vertical elevation, z position. VDOP is basically twice the value of HDOP. Generally, the

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more satellites detected, the smaller the DOP values and hence the smaller the positioning errors [5].

Position augmentation of GPS is a technique to improve positioning accuracy with the aid of removing positioning errors that caused by the signal propagation errors and clock biases. The position augmentation methods of GPS which are DGPS and RTK (Real Time Kinematics) are widely used to provide the better improvements on the positioning accuracy [6-8]. However, the systems are expensive to implement compared to the existing GPS [9].

DGPS was designed for alleviating the systematic error of Selective Availability (SA). The positioning error can be improved to about 10cm. DGPS consists of Reference Station and Rover Station [10]. In Figure 2, Reference Station is stationary situated at a fixed and known location for errors calculation between known and computed positioning data. Next, the errors correction will then be transferred to Rover Station for allevating the positioning errors and improving positioning accuracy. Position domain of DGPS can be used for estimated correction [11].

In this paper, average of errors, range of errors, number of satellites detected, HDOP, VDOP and improvement on DGPS will be discussed.

Mathematical Modeling

Position domain of DGPS is very simple to understand where the difference the known and measured position is calculated and then to augments the position, the calculated position difference is added to the measurement of rover [12].

In position domain of DGPS, the computed coordinates, $\vec{X}_{RS}$ is subtracted from the known coordinates, $\vec{X}_{RS,known}$ of reference station. The position difference is denoted as positioning error, δ_X.

$$\vec{\delta}_X = \vec{X}_{RS,known} - \vec{X}_{RS} \quad (1)$$

The average of the positioning errors, δ_{Xi} are calculated by the summation of positioning errors, $\Sigma\vec{\delta}_X$ divided by the total number of positioning errors, *N*.

$$\delta_{Xi} = \frac{\Sigma\vec{\delta}_X}{N} \quad (2)$$

The error corrections, $\vec{\delta}_X$ are then applied to the measured position from rover station, $\vec{X}_{rover,measured}$ which is used for mitigating the position error, and improving the accuracy of positioning. The rover with DGPS localisation is denoted as $\vec{X}_{rover,DGPS}$.

$$\vec{X}_{rover,DGPS} = \vec{X}_{rover,measured} + \vec{\delta}_X \quad (3)$$

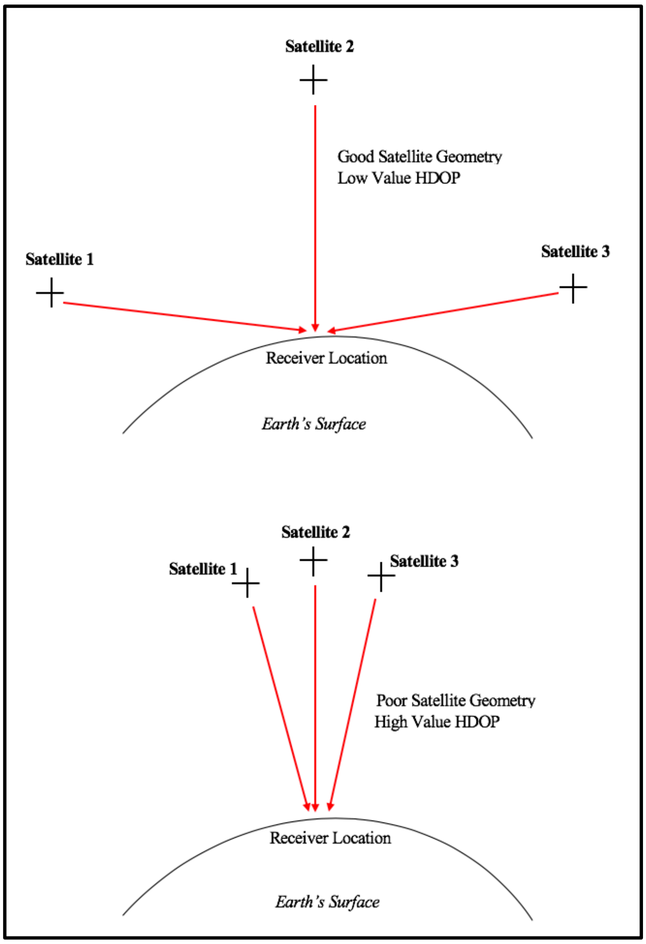

Figure 1. Low HDOP vs high HDOP.

Flowchart of the DGPS Experiment

Figure 3 shows the flow chart for carrying out the DGPS experiment. First, DGPS algorithm which is the mathematical modelling for position domain of DGPS is required to understand. For the DGPS experiment, there are two stations required to setup up which are Reference Station and Rover Station. Both stations are required to have the GPS receiver for collecting the positioning data. For Reference Station, data collected is used for errors calculation and then the average and range of errors are analysed and discussed. The errors correction from Reference Station is then transferred to Rover Station for improving the positioning data. Number of satellites detected, HDOP (Horizontal Dilution of Precision) and VDOP (Vertical Dilution of Precision) are analysed and discussed together with the DGPS improvement on the rover. The details of experimental setup of Reference Station and Rover Station will be explained on the next section.

Reference Station

DGPS operation uses a Reference Station at a fixed and known location to calculate and broadcast the error corrections to Rover Station, resulting in improved the rover's positioning accuracy [13-14]. An own-built Android App "Curent Coordinate" as shown in Figure 4 is built via MIT App Inventor to collect the positioning data and time. After the apps is built, an apk file is required to download using Android phone and install on it. The apps will be used together with "Auto Clicker" apps for auto-collecting the positioning data. "Auto Clicker" apps can be downloaded from Google Play Store and there are many types of auto clicker apps for user to choose.

Figure 4 shows the layout of the "Current Coordinates" apps. The "Current Coordinates" apps shows the time (in hours : minutes : seconds), latitude, x and longitude, y. To make the apps functionable, the location services of the phone is required to turn on so the location information can only be received. With the location services, latitude, x and longitude, y will be shown accordingly based on the location. The latitude, x and longitude, y at the same location would occur changes from time to time due to the accuracy of GPS.

Figure 5 shows the experimental flow chart of Reference Station. An Android phone with installed "Current Coordinates" and "Auto Clicker" apps are required for the experiment of Reference Station. Next, the location service on phone is required to turn on for receiving the location information. After that, the location where the phone is fixed is checked on google maps. It is important for error calculations. Next, "Current Coordinates" apps is opened to check the functionality. When the positioning data is receiving on the apps, "Auto Clicker" apps is then used to collect the positioning data every second during the experiment. The positioning data collected will then be used for calculating the errors and analysing the average and range of the error. The results will be explained in the next section.

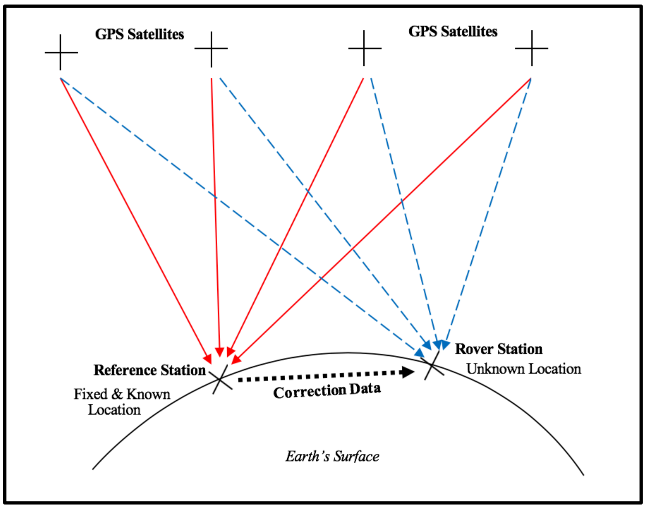

Figure 2. Principal scheme of DGPS.

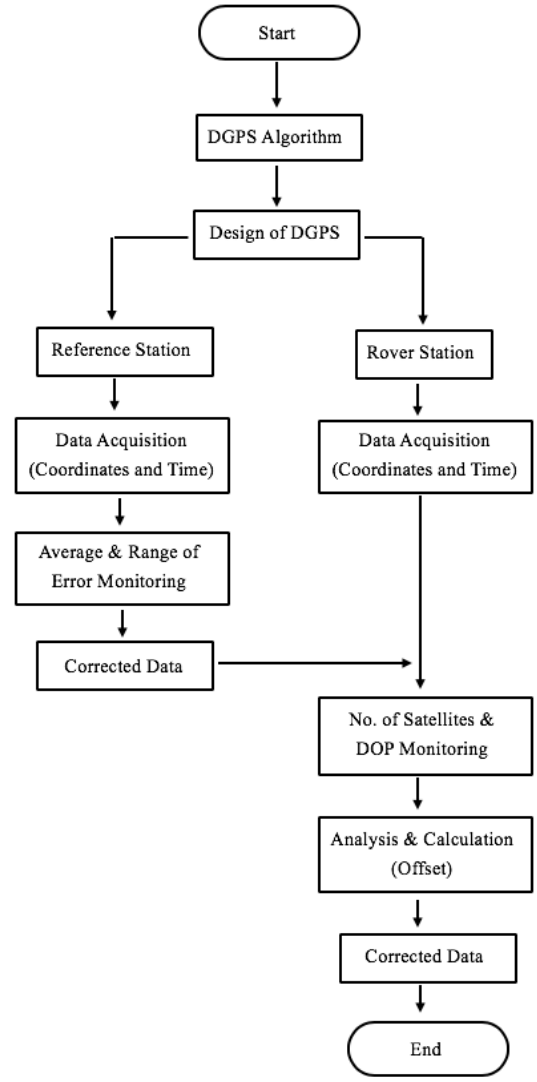

Figure 3. Flowchart of DGPS experiment.

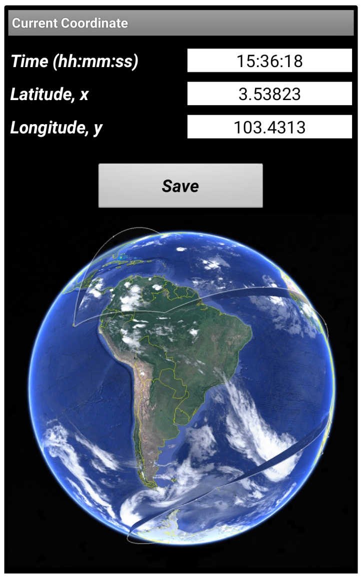

Figure 4. Own-built Android apps "Current Coordinate".

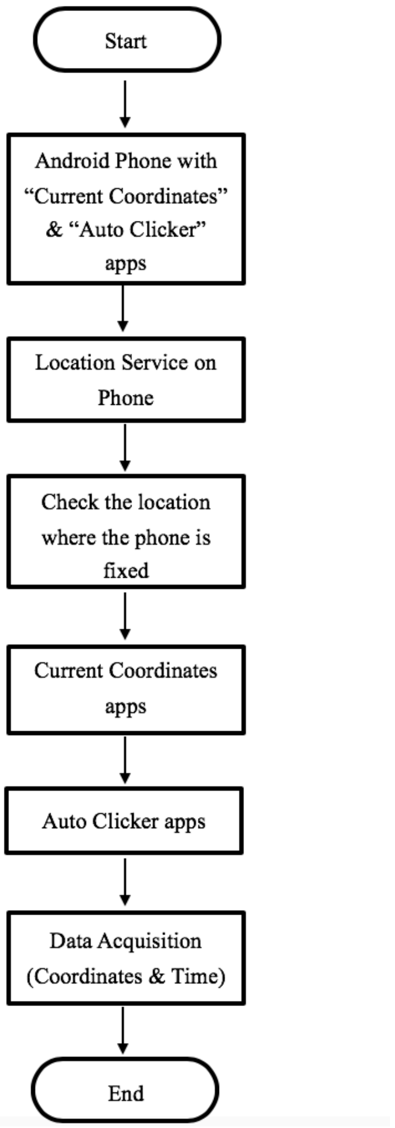

Figure 5. Experimental flowchart of reference station.

Rover Station

In Rover Station, DGPS correction information is transferred from Reference Station for alleviating the positioning error to improve the rover's localisation. Experimental Setup of Rover Station (Rover at home station) is as shown in Figure 6. 1972 Ford Bronco Ascender ™ 1/10 RTR is used for the experimental setup. It is a RC (Remote Control) based rover and is modified to be an unmanned ground vehicles (UGV). Components such as GPS module, radio telemetry, power module, receiver, safety swtich, buzzer, servo and ESC motors are connected to Pixhawk 2.4.8 controller. "Mission Planner" software is used to setup the rover for the autonomous mission [15].

Figure 7 shows the experimental layout of rover station. Laptop with QGroundControl software is connected to the rover system for observing and logging the data. During the experiment, few cameras are setup to record and observe the rover's motion. The rover at the home station, H will move from point 1 to point 6 according to what had been set on the QGroundControl software. Rover uses the GPS module to indicate the positioning and moving. The rover will undergoes 5 cycles per day for the data collection. The results are analysed and shown in the next section.

Figure 8 shows the autonomous mission via QGroundControl Software. The rover will move according to the waypoints with the aid of GPS receiver on the rover [16].

Day 1

Figure 9 and Figure 10 show the graph of error in latitude, x (in m) versus time (s) and the graph of error in longitude, y (in m) versus time (s) respectively. From the Figure 9, it can be seen that the minimum and maximum of error in latitude, x are -2.22m and 2.22m respectively which have the range of 4.44m. From Figure 10, it can be seen that the minimum and maximum of error in longitude, y are -5.55m and 3.33m, respectively, which have the range of 8.88m. The large range on errors occurred might due to weather and unstable of GPS system on GPS sensor.

Figure 11 shows the graph of no. of satellite detected versus time (s). It can be seen that the satellite detected in between 17 and 20. Furthermore, the most detected satellites are 20.

Figure 12 and Figure 13 show the graph of HDOP versus time (s) and the graph of VDOP versus time (s) respectively. From Figure 12, it can be seen that the HDOP over the time has the range within 0.55m and 0.62m. The average of HDOP over the time is 0.57m. From Figure 13, it can be seen that the VDOP over the time has the range within 0.93m and 1.23m. The average of VDOP over the time is 1.07m. The number of satellites will affect the value of HDOP and VDOP over the time. Furthermore, it will directly affect the accuracy on GPS.

Figure 14 and Figure 15 show the comparison between latitude, x in GPS and DGPS versus time (s) the comparison between longitude, y in GPS and DGPS versus time (s) respectively. From Figure 14, it shows the average of error of -0.281m in GPS and this means that the DGPS has improved by -0.281m. From Figure 15, it shows the average of error of 0.159m in GPS and this means that the DGPS has improved by 0.159 m.

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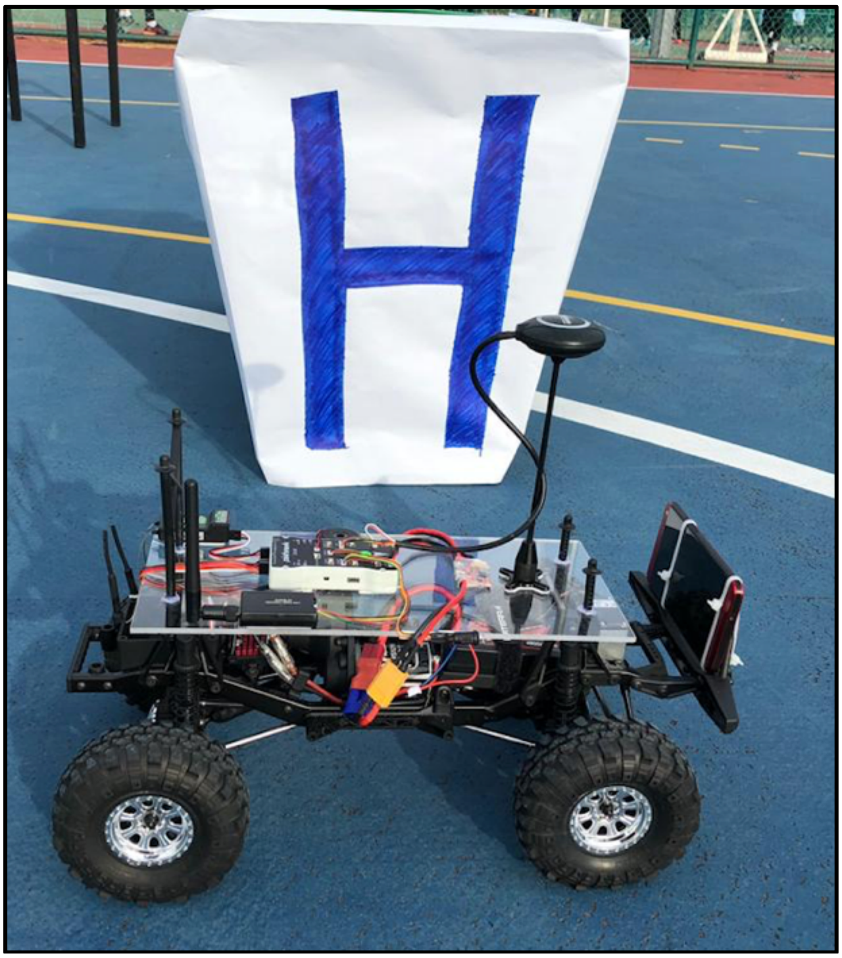

Figure 6. Experimental setup of rover station (rover at home station).

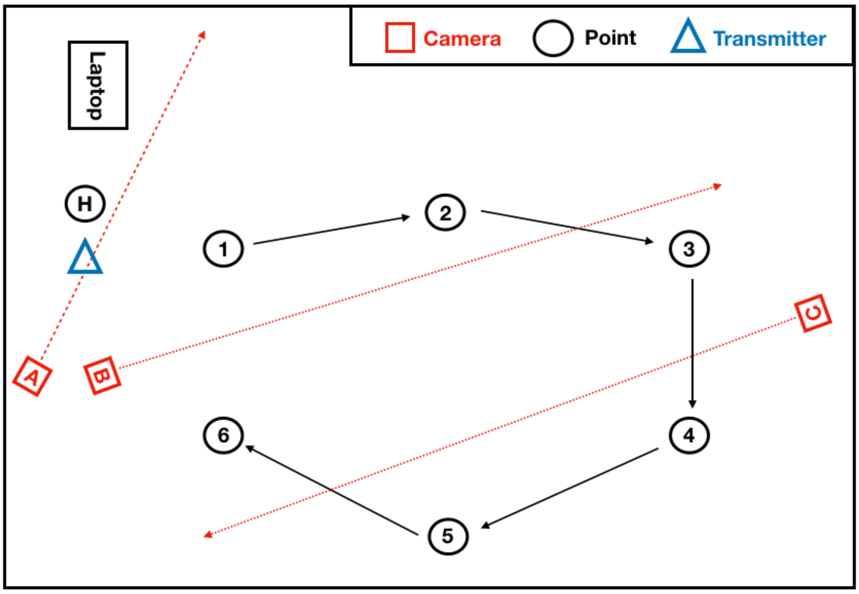

Figure 7. Experimental layout of rover station.

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Figure 8. Autonomous mission via QGroundControl Software.

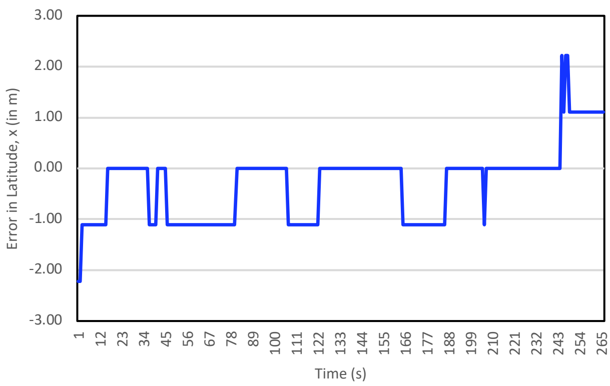

Figure 9. Error in Latitude, *x*, (in m) vs Time (s).

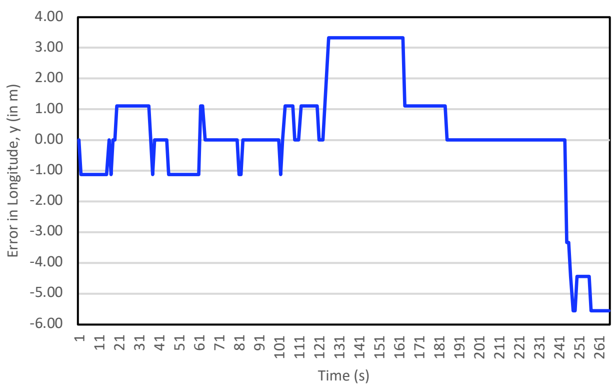

Figure 10. Error in Longitude, *y*, (in m) vs Time (s).

Day 2

Figure 16 and Figure 17 show the graph of error in latitude, *x* (in m) versus time (s) and the graph of error in longitude, *y* (in m) versus time (s) respectively. From Figure 16, it can be seen that the minimum and maximum of error in latitude, *x* are -3.33m and 3.33m respectively which have the range of 6.66m. From Figure 17, it can be seen that the minimum and maximum of error in longitude, *y* are -3.33m and 2.22m, respectively, which have the range of 5.55m. The large range on errors occurred might due to weather and unstable of GPS system on GPS sensor.

Figure 18 shows the graph of no. of satellite detected versus time (s). It can be seen that the satellites detected are in between 18 and 20. Furthermore, the most detected satellites are 20.

Figure 19 and Figure 20 show the graph of HDOP versus time (s) and the graph of VDOP versus time (s), respectively. From Figure 19, it can be seen that the HDOP over the time has the range within 0.56m and 0.63m. The average of HDOP over the time is 0.60m. From Figure 20, it can be seen that the VDOP over the time has the range within 0.94m and 1.26m. The average of VDOP over the time is 1.07m. The number of satellites will affect the value of HDOP and VDOP over the time. Furthermore, it will directly affect the accuracy on GPS.

Figure 21 and Figure 22 show the comparison between longitude, y in GPS and DGPS versus time (s) and the comparison between longitude, y in GPS and DGPS versus time (s) respectively. From Figure 21, it shows the average of error of 0.287m in GPS and this means that the DGPS has improved by 0.287m. From Figure 22, it shows the average of error of -0.618m in GPS and this means that the DGPS has improved by -0.619m.

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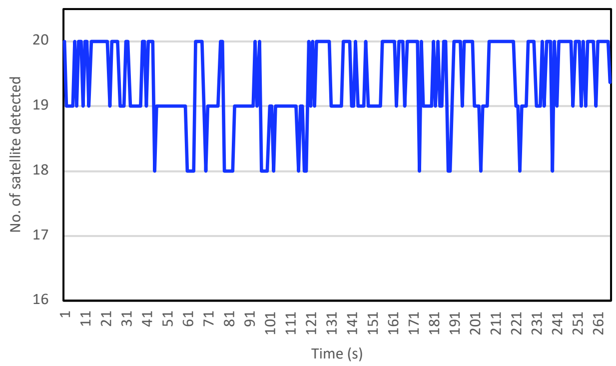

Figure 11. No. of satellite detected vs Time (s).

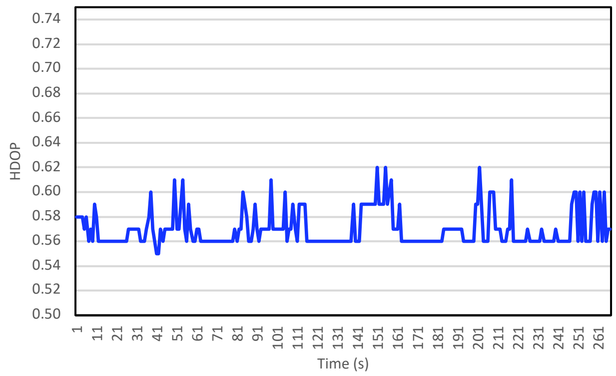

Figure 12. HDOP vs Time (s).

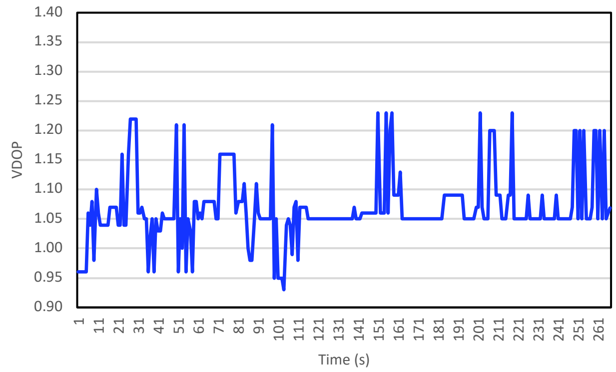

Figure 13. VDOP vs Time (s).

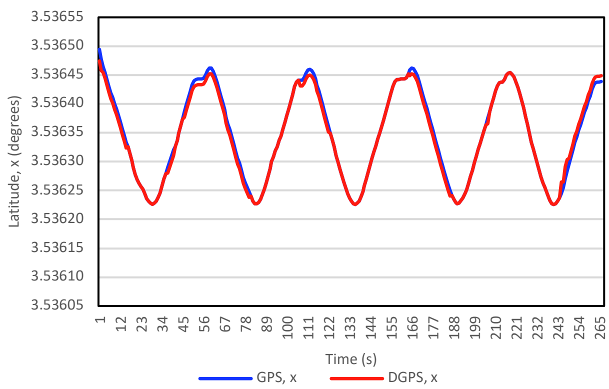

Figure 14. Comparison between Latitude, x, in GPS and DGPS vs Time (s).

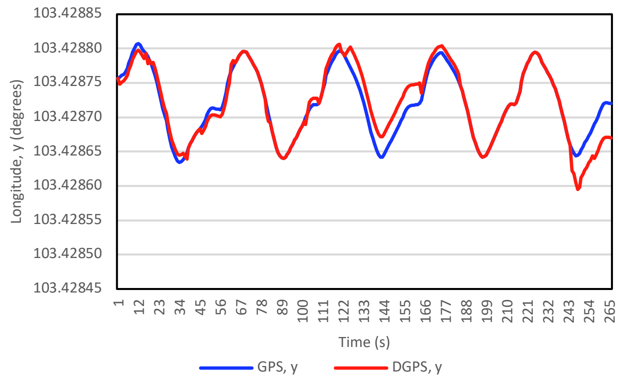

Figure 15. Comparison between Longitude, y, in GPS & DGPS vs Time (s).

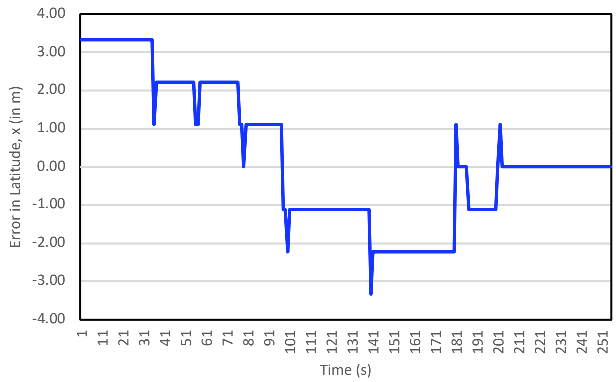

Figure 16. Error in Latitude, x, (in m) vs Time (s).

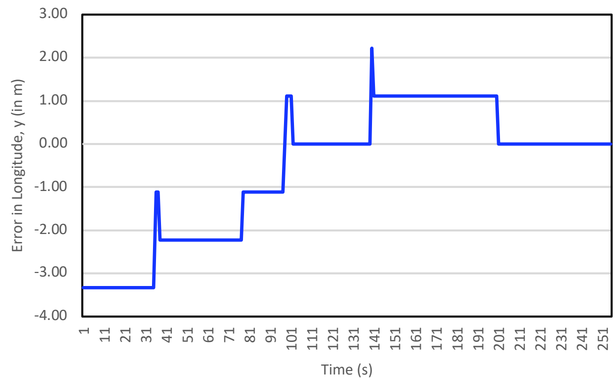

Figure 17. Error in Longitude, y, (in m) vs Time (s).

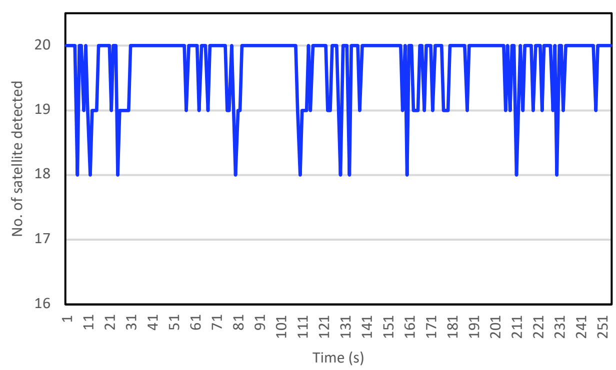

Figure 18. No. of satellite detected vs Time (s).

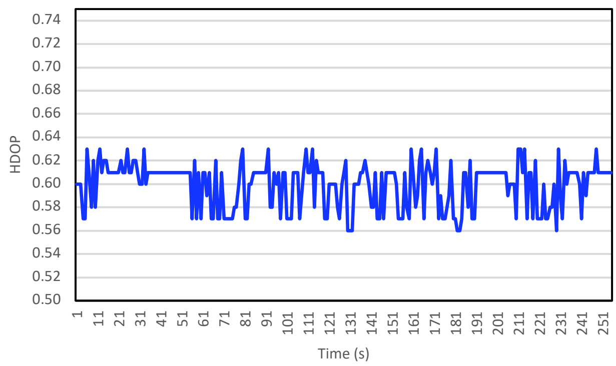

Figure 19. HDOP vs Time (s).

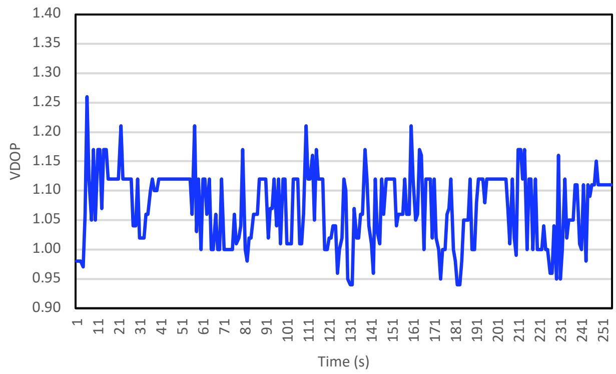

Figure 20. VDOP vs Time (s).

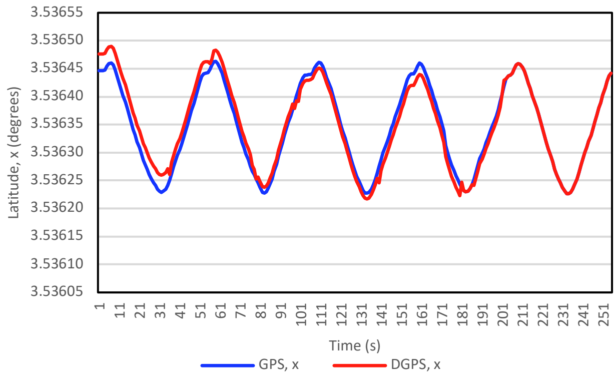

Figure 21. Comparison between Latitude, x, in GPS & DGPS vs Time (s).

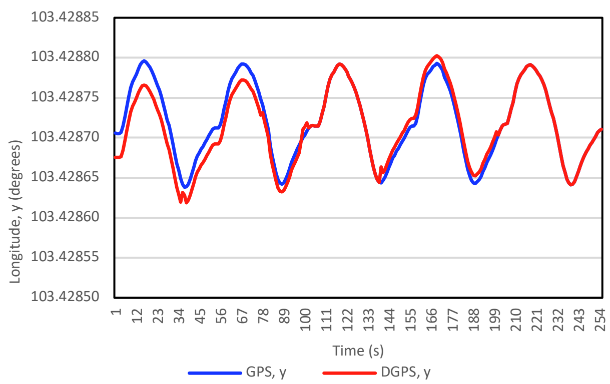

Figure 22. Comparison between Longitude, y, in GPS & DGPS vs Time (s).

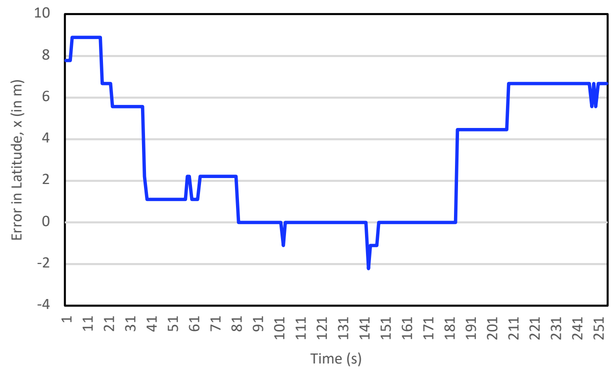

Figure 23. Error in Latitude, x (in m) vs Time (s).

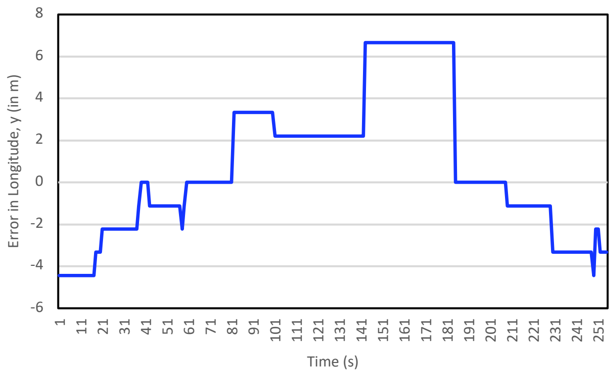

Figure 24. Error in Longitude, y (in m) vs Time (s).

Day 3

Figure 23 and Figure 24 show the graph of error in latitude, x (in m) versus time (s) and the graph of error in longitude, y (in m) versus time (s) respectively. From Figure 23, it can be seen that the minimum and maximum of error in latitude, x are -2.22 m and 8.88 m respectively which have the range of 11.1 m. From Figure 24, it can be seen that the minimum and maximum of error in longitude, y are -4.44 m and 6.66m, respectively, which have the range of 11.1 m. The large range on errors occurred might due to weather and unstable of GPS system on GPS sensor.

Figure 25 show the graph of number of satellites detected versus time (s). It can be seen that the satellite detected in between 18 and 20. Furthermore, the most detected satellites are 20.

Figure 26 and Figure 27 show the graph of HDOP versus time (s) and the graph of VDOP versus time (s), respectively. From Figure 26, it can be seen that the HDOP over the time has the range within 0.55 m and 0.65 m. The average of HDOP over the time is 0.57 m. From Figure 27, it can be seen that the VDOP over the time has the range within 0.96m and 1.30 m. The average of VDOP over the time is 1.07 m.

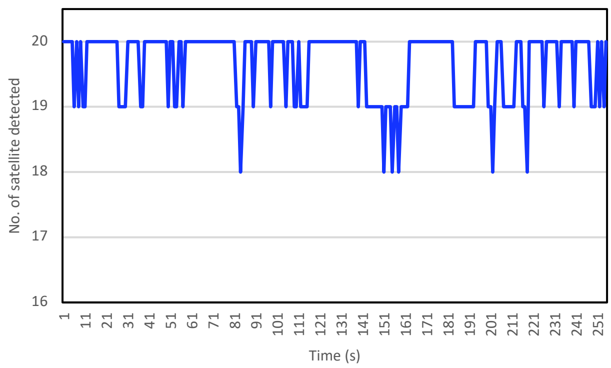

Figure 25. Number of satellite detected vs Time (s).

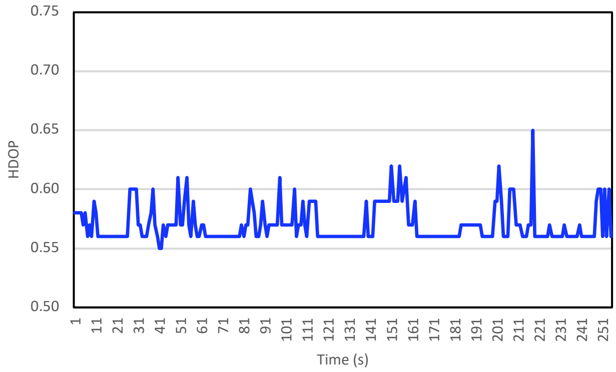

Figure 26. HDOP vs Time (s).

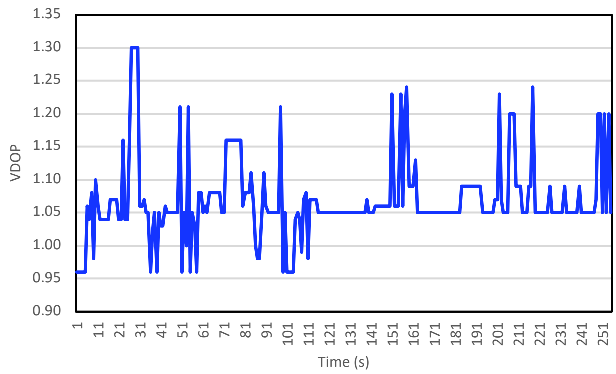

Figure 27. VDOP vs Time (s).

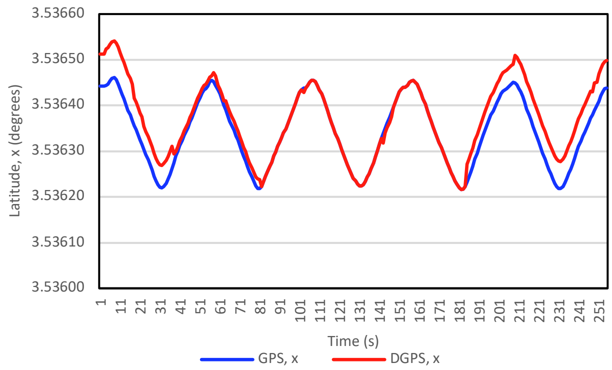

Figure 28. Comparison between Latitude, *x* in GPS and DGPS vs Time (s).

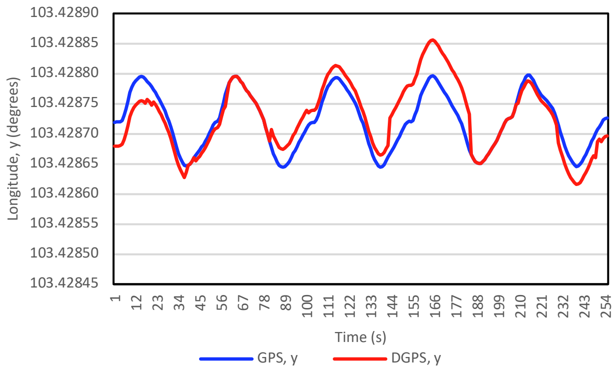

Figure 29. Comparison between Longitude, *y* in GPS and DGPS vs Time (s).

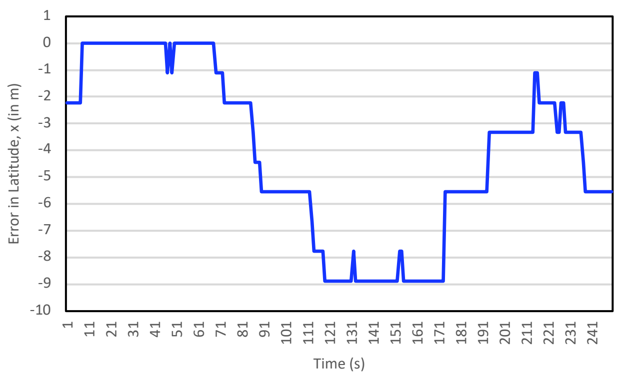

Figure 30. Error in Latitude, *x* (in m) vs Time (s).

Figure 28 and Figure 29 show the comparison between longitude, *y* in GPS and DGPS versus time (s) and the comparison between longitude, y in GPS and DGPS versus time (s), respectively. From Figure 28, it shows the average of error of 2.925 m in GPS and this means that the DGPS has improved by 2.925 m. From Figure 29, it shows the average of error of 0.718 m in GPS and this means that the DGPS has improved by 0.718 m. The number of satellites will affect the value of HDOP and VDOP over the time. Furthermore, it will directly affect the accuracy on GPS.

Day 4

Figure 30 and Figure 31 show the graph of error in latitude, x (in m) versus time (s) and the graph of error in longitude, y (in m) versus time (s) respectively From Figure 30, it can be seen that the minimum and maximum of error in latitude, x are -8.88m and 0m respectively which have the range of 8.88m. From the Figure 31, it can be seen that the minimum and maximum of error in longitude, y are -3.33m and 9.99m respectively which have the range of 13.32m. The large range on errors occurred might due to weather and unstable of GPS system on GPS sensor.

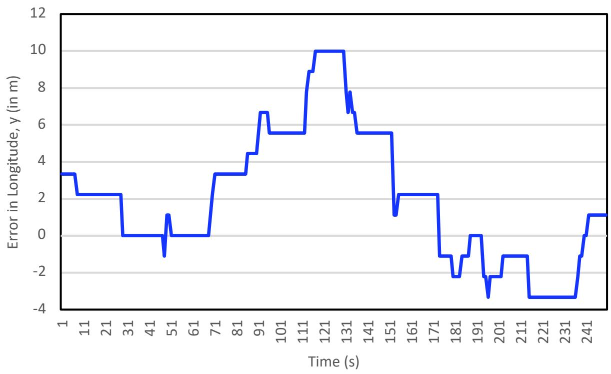

Figure 31. Error in Longitude, y (in m) vs Time (s).

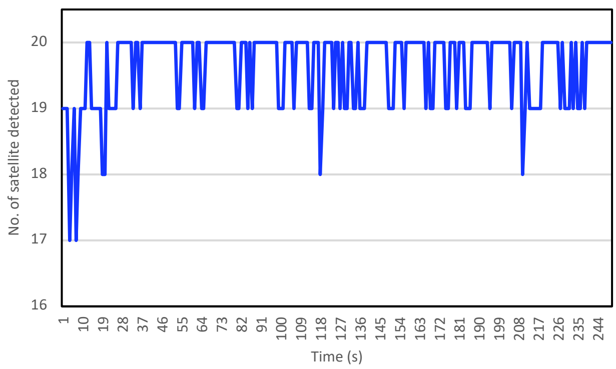

Figure 32. Number of satellite detected vs Time (s).

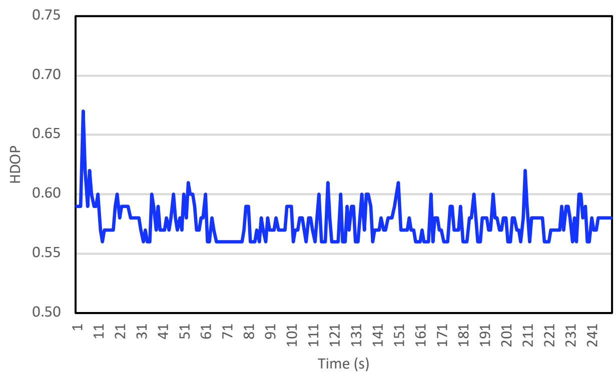

Figure 33. HDOP vs Time (s).

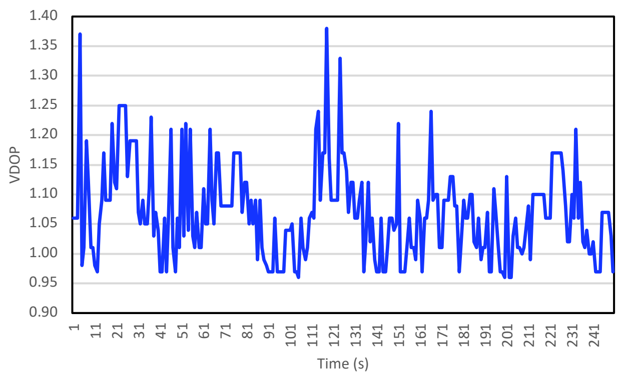

Figure 34. VDOP vs Time (s).

Figure 32 shows the graph of number of satellites detected versus time (s). It can be seen that the satellite detected in between 17 and 20. Furthermore, the most detected satellites are 20.

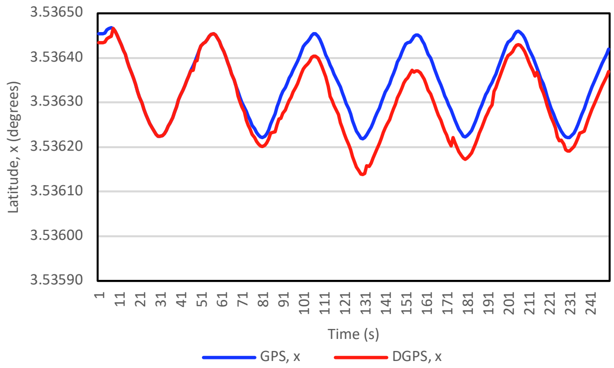

Figure 35. Comparison between Latitude, x in GPS and DGPS vs Time (s).

Figure 33 and Figure 34 show the graph of HDOP versus time (s) and the graph of VDOP versus time (s) respectively. From Figure 33, it can be seen that the HDOP over the time has the range within 0.56m and 0.67. The average of HDOP over the time is 0.58m. From Figure 34, it can be seen that the VDOP over the time has the range within 0.96m and 1.38m. The average of VDOP over the time is 1.07m. The number of satellites will affect the value of HDOP and VDOP over the time. Furthermore, it will directly affect the accuracy on GPS.

Figure 35 and Figure 36 show the comparison between longitude, y in GPS and DGPS versus time (s) and the comparison between longitude, y in GPS and DGPS versus time (s), respectively. From Figure 35, it shows the average of error of -4.165 m in GPS and this means that the DGPS has improved by -4.165 m. From Figure 36, it shows the average of error of 1.998 m in GPS and this means that the DGPS has improved by 1.998 m.

From Table 1, it can be seen that Day 1 has the smallest error in latitude, x and longitude, y which are -0.282 m and 0.159 m, respectively, and the error in latitude, x and longitude, y increasing followed by Day 2 (x = 0.287 m and y = -0.618 m) , Day 3 (x = 2.925 m and y = 0.718 m), and Day 4 (x = -4.165 m and y = 1.998 m). It means that the Day 4 has the best improvement on DGPS as it has alleviate the most errors on the rover's localisation.

Besides, the number of satellites detected during the experiment affected the value of HDOP and VDOP over the time. In theoretical, greater the number of satellites, better the value of HDOP and VDOP. It means that the less DOP (Dilution of Precision), the better GPS signals. In Table 1, it can be seen that there are the range of within 18 and 20 satellites detected in Day 1, 2 and 3 but only 17 to 20 satellites detected in Day 4. Day 4 has the larger range of satellites detected which cause the larger error of positioning data.

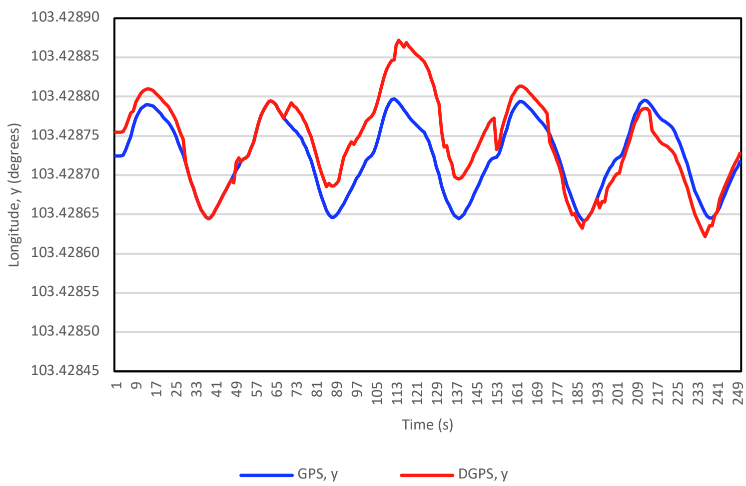

Figure 36. Comparison between Longitude, *y* in GPS and DGPS vs Time (s).

Table 1. Comparison of data at 8 am in four different days.

Day		1	2	3	4
No. of Satellite		18-20	18-20	18-20	17-20
HDOP	Min	0.55	0.56	0.55	0.56
	Max	0.62	0.63	0.65	0.67
	Average	0.57	0.60	0.57	0.58
VDOP	Min	0.93	0.94	0.96	0.96
	Max	1.23	1.26	1.30	1.38
	Average	1.07	1.07	1.07	1.07
Error in Latitude, *x* (m)	Min	-2.22	-3.33	-2.22	-8.88
	Max	2.22	3.33	8.88	0
	Range	4.44	6.66	11.1	8.88
	Average	-0.281	0.287	2.925	-4.165
Error in Longitude, *y* (m)	Min	-5.55	-3.33	-4.44	-3.33
	Max	3.33	2.22	6.66	9.99
	Range	8.88	5.55	11.1	13.32
	Average	0.159	-0.618	0.718	1.998

Compare with the value of HDOP, it can be seen that Day 2 has the highest average of HDOP value which are 0.60 but it does not mean that it will occurred the larger positioning error because it still has the smaller range of HDOP value and smaller maximum HDOP value compared to Day 3 and Day 4.

With compared the value of VDOP, it can be seen that there are the same average of VDOP value in 4 different days. Although the averages of VDOP are the same in 4 different days, Day 1 has the smallest range of VDOP (min = 0.93 and max = 1.23) followed by Day 2 (min = 0.94 and max = 1.26), Day 3 (min = 0.96 and max = 1.30) and Day 4 (min = 0.96 and = 1.38).

Conclusion

From the results, it can be concluded that the GPS positioning at the same time in different days has different positioning accuracy so DGPS method is required to be applied for improving the localisation. Besides, it can be said that the greater the number of satellites detected, the smaller the value of HDOP and VDOP which provide the better GPS signals for receiving positioning data. The number of satellites detected might due to unstable GPS system and climatic change as well. But with the DGPS, the errors can be calculated at Reference Station and then transfer to Rover Station for alleviating the positioning errors. DGPS method can be applied on autonomous vehicles for navigation tracking since it is more accurate compared to GPS system as the autonomous vehicles need more accurate positioning data to prevent accident on the road.

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