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EVALUATION OF THE ACCURACY OF GLOBAL POSITIONING SYSTEM (GPS) SPEED MEASUREMENT VIA GPS SIMULATION

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ABSTRACT

In this study, Global Positioning System (GPS) simulation is employed to evaluate the accuracy of GPS speed measurements. The two methods of GPS speed measurement, trackpoints and Doppler shift, are compared for two conditions of tests: 1) Normal scenario with the full range of available GPS satellites; 2) Obstruction scenario with only six GPS satellites available. For the trackpoints method, significant errors are observed, due to positioning errors caused by the GPS receiver's user equivalent ranging error (UERE). The errors increased with increasing speed due to increasing length of zig-zag lines connecting the trackpoints, which is caused by the receiver's positioning errors. The Doppler shift method generated much smaller errors for the normal scenario (maximum of 0.238 km/h for speeds of up to 1,800 km/h), as it is insensitive to the UERE of GPS receivers. Decrease of available GPS satellites in the obstruction scenario also caused increase of error for the trackpoints method due to increased position dilution of precision (PDOP) and thus, increased UERE. For the Doppler shift method, the increase of error was much smaller (maximum of 0.254 km/h for speeds of up to 1,800 km/h), indicating that change in GPS satellite geometry has limited effect on this method.

Keywords: *Global Positioning System (GPS) simulation; speed; trackpoints and Doppler shift; user equivalent ranging error (UERE); position dilution of precision (PDOP).*

1. INTRODUCTION

Global Navigation Satellites Systems (GNSS) receivers are becoming smaller, cheaper and more reliable, and hence, are being increasingly used for measurement of speed. Speed is defined as the rate of change of position, with its determination requiring measurements of distance and time components (Witte & Wilson, 2004). There are two methods for computation of GNSS speed measurement, which are trackpoints and Doppler shift.

For GNSS speed measurement via trackpoints, the GNSS receiver records a series of computed positions (trackpoints) at regular time intervals, which are then used to compute the speed. However, each trackpoint is suspect to variable errors, resulting in the computed speed being less accurate and reliable. Due to trackpoint inaccuracies, the line connecting all the trackpoints would be a zig-zag, even if the real path is a smooth or straight line. Since the length of a zig-zag line is always longer than the corresponding smooth or straight line, the accumulated distance and thus, the computed average speed is always overestimated as compared to the real speed (Chalko, 2007; Huang *et al*., 2013; Gaglione, 2015).

For GNSS speed measurement via Doppler shift, the GNSS receiver continuously tracks the carrier frequencies of the available GNSS satellites. The difference between the known satellite carrier frequency and the frequency determined at the receiver, known as the Doppler shift, is directly proportional to the speed of the receiver along the direction to the satellite. A minimum of four tracked satellites are required to determine the 3D speed vector of the receiver. A significant advantage of Doppler speed measurement is that it is insensitive to distances from satellites, phase delays and a number of factors that are major sources of error for GNSS positioning using satellite range measurement. However, its accuracy is not constant as it is dependent on the number and geometrical distribution of available satellites (Zhang *et al*., 2006; Chalko, 2007; Huang *et al*., 2013; Gaglione, 2015).

A number of studies have been conducted to evaluate the accuracy of GNSS speed measurements (Witte & Wilson, 2004; Chalko, 2007; Huang *et al*., 2013; Little *et al*., 2013; Steinmetz *et al*. 2014; Bai *et al*., 2015). These studies were conducted via field evaluations using live GNSS signals. However, such field evaluations are subject to various error parameters, such as ionospheric and tropospheric delays, GNSS satellite clock and ephemeris errors, GNSS satellite positioning and geometry, radio frequency interference (RFI), and obstructions and multipath, which are uncontrollable by users (Aloi *et al.* 2007; Kou & Zhang 2011; Pozzobon *et al.*, 2013).

The ideal GNSS receiver evaluation methodology would be using a GNSS simulator, which can be used to generate multi-satellite GNSS configurations, transmit GNSS signals that simulate real world scenarios, and adjust the various error parameters. This would allow for the evaluations of GNSS receiver performance under various repeatable conditions, as defined by users. As the evaluations are conducted in controlled laboratory environments, they will not be inhibited by unwanted signal interferences and obstructions (Aloi *et al.* 2007; Kou & Zhang 2011; Pozzobon *et al.*, 2013). In previous studies, Global Positioning System (GPS) simulation was used to evaluate the vulnerabilities of GPS to radio frequency interference (RFI) (Dinesh *et al*., 2012, 2014a), multipath (Dinesh *et al*., 2013, 2014b), GPS satellite clock error (Dinesh *et al*., 2015a) and power consumption (Dinesh *et al*., 2015b).

In this study, GPS simulation is employed to evaluate the accuracy of GPS speed measurements. Both methods of GNSS speed measurement, trackpoints and Doppler shift, are compared for two conditions of tests: 1) Normal scenario with the full range of available GPS satellites; 2) Obstruction scenario with only six GPS satellites available.

2. METHODOLOGY

The apparatus used in the study are an Aeroflex GPSG-1000 GPS simulator (Aeroflex, 2010), a notebook running GPS Diagnostics v1.05 (CNET, 2004) and a Garmin GPSmap 60CSx handheld GPS receiver (Garmin, 2007). The GPS receiver employs the GPS L1 coarse acquisition (C/A) signal, which is an unencrypted civilian GPS signal widely used by various GPS receivers. The signal has a fundamental frequency of 1,575.42 MHz and a code structure which modulates the signal over a 2 MHz bandwidth (DOD, 2001; Kaplan & Hegarty, 2006; USACE, 2011). The study is conducted in STRIDE's mini-anechoic chamber (Kamarulzaman, 2010) to avoid external interference signals and unintended multipath errors. The test setup employed is as shown in Figure 1. Simulated GPS signals are generated using the GPS simulator and transmitted via the coupler. The following assumptions are made for the tests conducted:

i) No ionospheric or troposheric delays
ii) No GPS satellite clock and ephemeris error
iii) No obstructions or multipath
iv) No interference signals.

The tests are conducted for coordinated universal time (UTC) times of 0000, 0300, 0600 and 0900 for the routes shown in Table 1. The almanac data for the periods is downloaded from the US Coast Guard's web site (USCG, 2015) and imported into the GPS simulator. The GPS signal power level is set at -130 dBm. The speeds used for the test are 0, 30, 100, 250, 500, 1000, 1,500 and 1,800 km/h. For each reading, the trackpoints and Doppler shift speed computed by the GPS receiver are recorded for a period of 15 min.

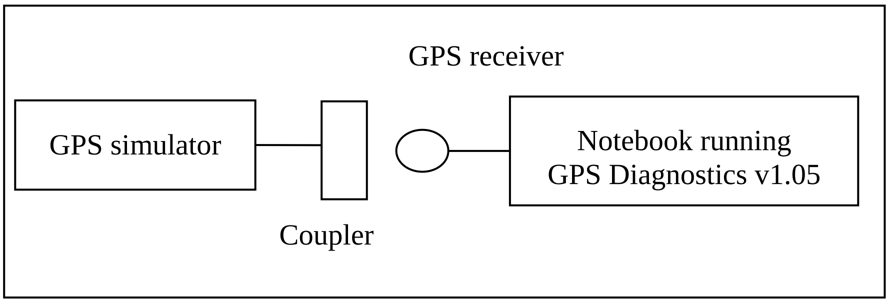

Figure 1: The test setup employed.

Table 1: The routes used for the tests conducted.

Start		Stop	
Kajang, Selangor, Malaysia	N 2° 58’ E 101° 48’	Hanoi, Vietnam	N 20° 54’ E 105° 49’
Denver, Colorado, US	N 39° 45’ W 105° 00’	Washington D.C., Washington, US	N 38° 54’ W 77° 2’
Cairns, Queensland, Australia	S 16° 55’ E 145° 46’	Canberra, Australian Capital Territory (ACT), Australia	S 35° 15’ E 149° 10’
Rio Gallegos, Argentina	S 51° 37’ W 69° 12’	Buenos Aires, Argentina	S 34° 35’ W 57° 30’

3. RESULTS & DISCUSSION

For the stationary condition, as shown in Table 2, the trackpoints method erroneously indicates that the GPS receiver is moving. This is due to the user equivalent ranging error (UERE) of the receiver, which is the total expected magnitude of position errors due to measurement uncertainties from the various error components for the receiver, such as receiver noise and antenna orientation (DOD, 2001; Kaplan & Hegarty, 2006; Worley, 2007; USACE, 2011). The errors generated result in the computed position of the receiver moving over time, depending on GPS coverage in terms of position dilution of precision (PDOP), which represents the effect of GPS satellite geometry on 3D positioning precision. A PDOP value of 1 is associated with an ideal arrangement of the satellite constellation. To ensure high-precision GPS positioning, a PDOP value of 5 or less is usually recommended. In practice, the actual PDOP value is usually much less than 5, with a typical average value in the neighbourhood of 2 (DOD, 2001; Kaplan & Hegarty, 2006; Dinesh *et al.*, 2010; USACE, 2011). Higher PDOPs would result in larger errors and hence, higher speeds. It is observed that the Doppler shift method is able to provide accurate results as it is insensitive to the UERE of GPS receivers.

For the moving condition, for the trackpoints method (Figure 2), it is observed that increase of speed causes increase of error. This is due to increasing length of zig-zag lines connecting the trackpoints, which is caused by the receiver’s positioning errors. For the Doppler shift method, increase of speed also causes increase of error, but the range of error is much smaller (maximum of 0.238 km/h) (Figure 3) as compared to the trackpoints method.

For the trackpoints method, the errors computed for the obstruction scenario (Figure 4) are higher as compared to the normal scenario. This is as the decrease of number of GPS satellites causes in increase of PDOP and hence, increase of the receiver’s UERE, resulting in less precise positioning. For the Doppler shift method, the increase of error is much smaller (maximum of 0.254 km/h) (Figure 5), indicating that change in GPS satellite geometry has limited effect on this method. This is consistent with the findings of Witte & Wilson (2004), who reported that the effect of satellite geometry on this method is not significant.

Table 2: Measured speeds for the stationary condition.

Location	UTC time	Average speed (km/h)			
		Normal		Obstruction	
		Trackpoints	Doppler	Trackpoints	Doppler
Kajang	0000	0.015	0	0.031	0
	0300	0.015	0	0.019	0
	0600	0.006	0	0.010	0
	0900	0.011	0	0.017	0
Denver	0000	0.015	0	0.023	0
	0300	0.015	0	0.033	0
	0600	0.005	0	0.016	0
	0900	0.012	0	0.031	0
Cairns	0000	0.015	0	0.023	0
	0300	0.018	0	0.033	0
	0600	0.007	0	0.012	0
	0900	0.012	0	0.030	0
Rio Gallegos	0000	0.017	0	0.031	0
	0300	0.014	0	0.022	0
	0600	0.012	0	0.019	0
	0900	0.016	0	0.025	0

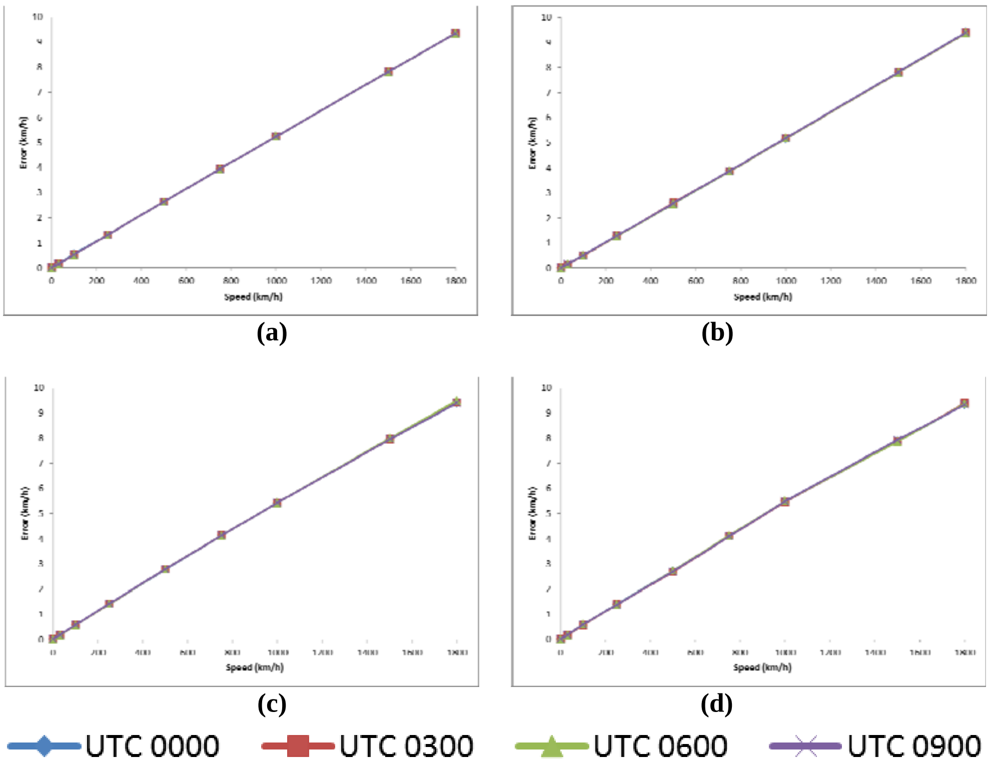

Figure 2: Errors for GPS speed measurement using the trackpoints method for the normal scenario for routes of: (a) Kajang-Hanoi (b) Denver-Washington D.C. (c) Cairns-Canberra (d) Rio Gallegos-Buenos Aires.

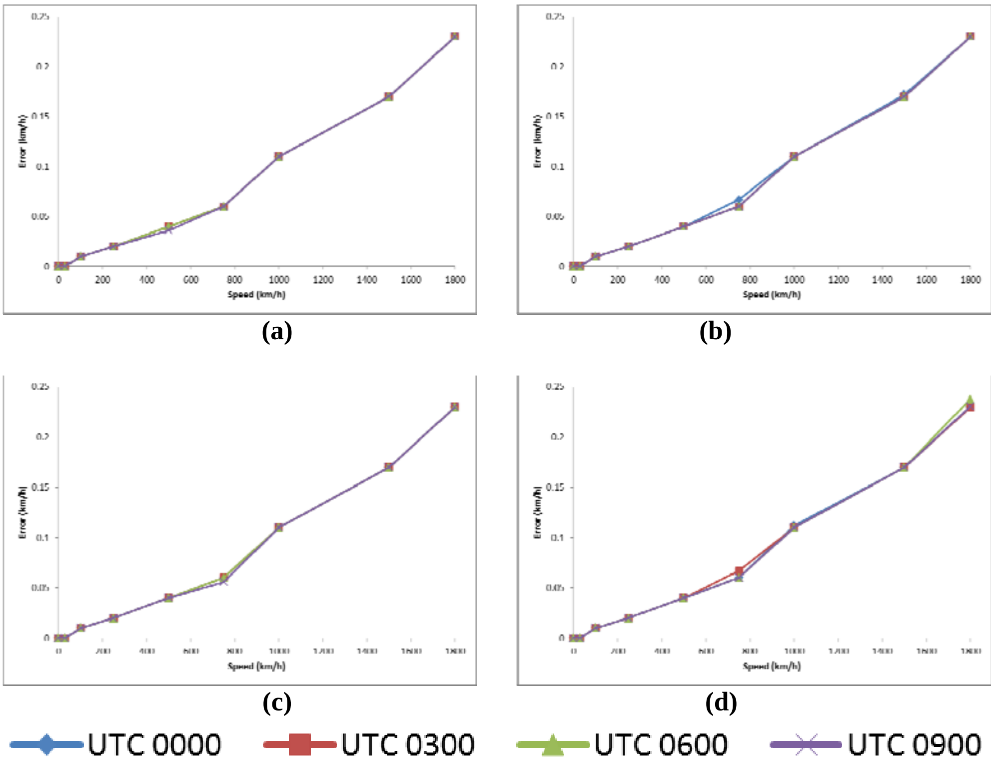

Figure 3: Errors for GPS speed measurement using the Doppler shift method for the normal scenario for routes of: (a) Kajang-Hanoi (b) Denver-Washington D.C. (c) Cairns-Canberra (d) Rio Gallegos-Buenos Aires.

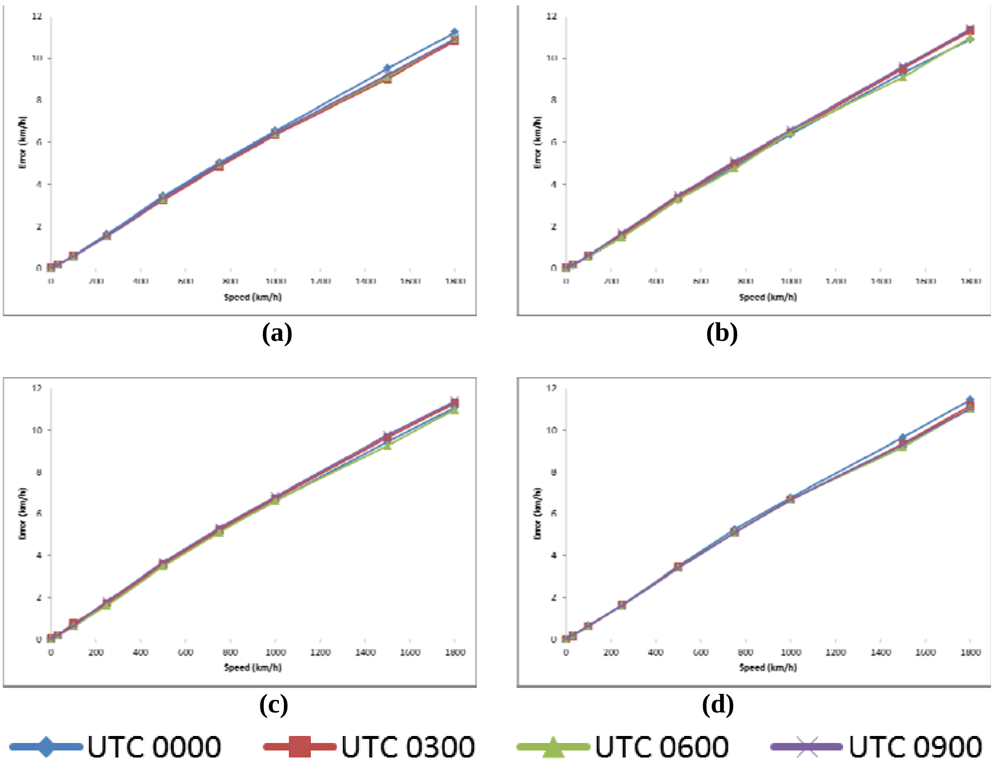

Figure 4: Errors for GPS speed measurement using the trackpoints method for the obstruction scenario for routes of: (a) Kajang-Hanoi (b) Denver-Washington D.C. (c) Cairns-Canberra (d) Rio Gallegos-Buenos Aires.

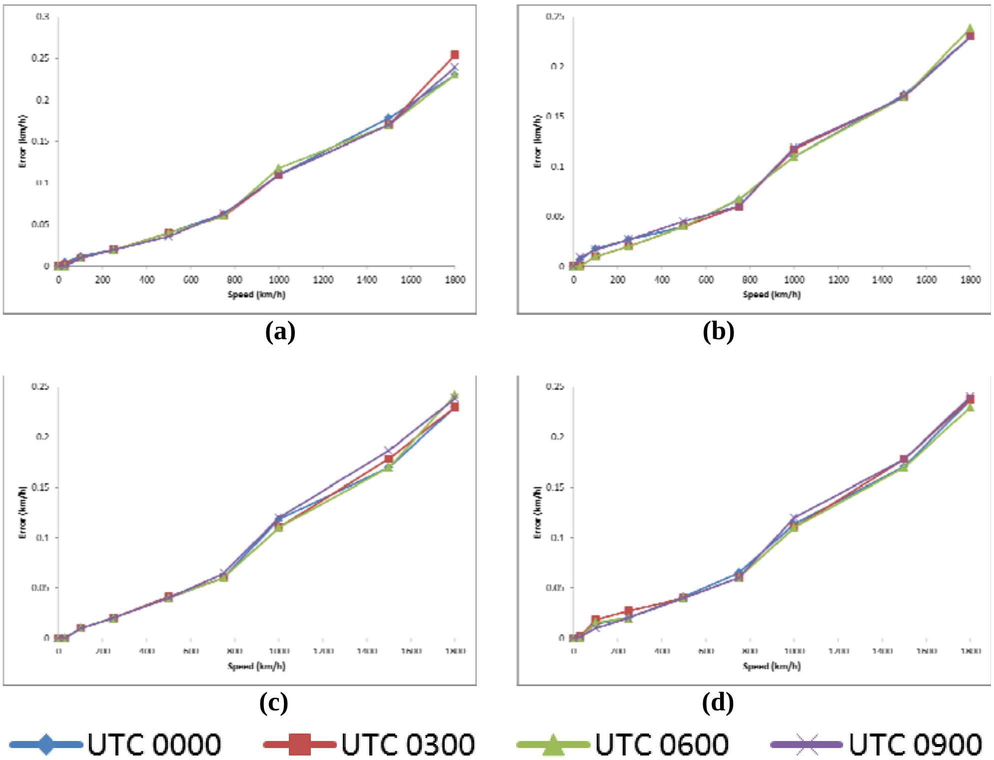

Figure 5: Errors for GPS speed measurement using the Doppler shift method for the obstruction scenario for routes of: (a) Kajang-Hanoi (b) Denver-Washington D.C. (c) Cairns-Canberra (d) Rio Gallegos-Buenos Aires.

The speed errors observed in this study are found to be smaller than corresponding errors reported in previous studies (Witte & Wilson, 2004, 2005; Chalko, 2007; Huang *et al*., 2013; Little *et al*., 2013; Steinmetz *et al*. 2014; Bai *et al*., 2015). This is as in this study, the effects of GPS vulnerabilities, such as ionospheric and tropospheric delays, GPS satellite clock and ephemeris error, multipath, and RFI, were not considered. Furthermore, the study was conducted for smooth straight line paths with consistent speed. It has been reported that rapid changes of speed and circular paths can degrade the accuracy of GPS speed measurement (Witte & Wilson, 2004; Huang *et al*., 2013; Steinmetz *et al*. 2014). To this end, further studies need to be conducted to evaluate the effects of various GPS vulnerabilities and movement types on the accuracy of GPS speed measurement in user-controlled scenarios.

4. CONCLUSION

In this study, GPS simulation was used to evaluate the two methods of GPS speed measurement, which are trackpoints and Doppler shift. For the trackpoints method, significant errors were observed, due to positioning errors caused by the GPS receiver's UERE. The errors increased with increasing speed due to increasing length of zig-zag lines connecting the trackpoints, which was caused by the receiver's positioning errors. The Doppler shift method generated much smaller errors for the normal scenario (maximum of 0.238 km/h for speeds of up to 1,800 km/h), as it is insensitive to the UERE of GPS receivers. Decrease of available GPS satellites in the obstruction scenario also caused increase of error for the trackpoints method due to increased PDOP and thus, increased UERE. For the Doppler shift method, the increase of error was much smaller (maximum of 0.254 km/h for speeds of up to 1,800 km/h), indicating that change in GPS satellite geometry has limited effect on this method. Further studies are proposed to evaluate the effect of various GPS vulnerabilities and movement types on the accuracy of GPS speed measurement in user-controlled scenarios.

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