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Testing the Accuracy of Autonomous GPS in Ground Speed Measurement

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Abstract: A hand-held Garmin eTrex Venture Global Positioning System (GPS) receiver operated in autonomous mode was used to investigate the accuracy of autonomous GPS in measuring ground speed. The accuracy of GPS-derived ground speed was tested by collecting and storing in a laptop computer, every 10 sec, ground speed data from the receiver at eight different ground speeds of a vehicle. The targeted ground speeds involved were 5, 10, 15, 20, 25, 30, 40 and 50 km h^{-1}. The vehicle's speedometer was used as an initial indicator of the ground speed. A pulse transmitter was utilized to detect the frequency, for every 10 sec, of a magnet fixed on one of the vehicle's wheels and passing by the transmitter every full rotation of the wheel. Data from the pulse transmitter was acquired and stored in a data logger. Given that the wheel's circumference was known, frequencies were used to calculate the ground speeds which were used as a reference. By the use of matching times of GPS and data logger data records, GPS-derived ground speeds were compared against the reference speed measurements. For nearly 600 data points comprising the data set for the eight test ground speeds, it was found that the error in GPS-derived ground speeds was, on the average, 1.27 km h^{-1} (less than 7%.) However, high fluctuations in vehicle's ground speed when, for example, turning greatly impacted this error. An error of -80.16% was produced due to a drop of vehicle's ground speed from 18.65 to 11.19 km h^{-1}. Results of steady state ground speed analysis revealed that the average error was less than 1 km h^{-1} (less than 5.3%), except for the 15 km h^{-1} data set where the average error reached 1.72 km h^{-1} (9.92%.)

Key words: GPS, ground speed measurement, vehicle ground speed

INTRODUCTION

In recent years, the satellite-based Global Positioning System (GPS) has won the recognition as an effective and efficient means of agricultural vehicle location determination. A guide to GPS was published by Hurn[1], which is useful to understand the theory and the operation of the system. The GPS is being used in an enormous and increasing array of applications that involve the management of individual agricultural fields and national natural resources in general. Availability and relatively low cost of GPS technology has made the precision agriculture concept more appealing to farmers. Precision agriculture includes the regulation of farming inputs, such as agricultural chemicals, to match the specific requirements of different areas of an agricultural field. One example is the study made by Al-Gaadi[2] where a real-time differentially corrected GPS, along with a Geographical Information System (GIS) herbicide management map, were utilized to automatically vary on-the-go the amount of herbicide application rate according to the field position of a ground field sprayer. Differential correction of GPS data was implemented for that study to eliminate the error due to the Selective Availability (S/A), which could cause an error of 30 m per satellite used in position calculation[3]. Regulation of farming inputs, such as seeds and agricultural chemicals, involves the agricultural vehicle ground speed as a major and determinant factor that directly affects the accuracy of the amount of application rate deposited into the area treated. A study conducted by Al-Gaadi and Ayers[4] revealed that, under field conditions, the ground speed of a sprayer measured by a speed radar sensor ranged between -7 to 4% of the desired speed, which resulted in an application rate error of -18 to 5% of the targeted rate. The GPS can provide a low-cost means to measure ground speed of different agricultural equipment for different agricultural applications and controls. However, the utilization of GPS-derived speed depends greatly on its accuracy. Guo and Zhang[5] reported that a DGPS with a position accuracy of 3 m 95% of the time provided a velocity accuracy of 0.51 m/s based on steady state Root Mean Squared (RMS) error. The authors provided no information as how the velocity accuracy of their GPS was determined. Han *et al.*[6] tested the dynamic position accuracy of DGPS receivers under linear parallel-tracking applications. Velocity data of the vehicle as determined by the DGPS receivers was recorded and was found to affect the pass and pass-to-pass position accuracy of the DGPS receivers tested. However, the accuracy of DGPS-derived velocity was not tested nor reported in their study. Li *et al.*[7] used DGPS to measure ground speed as this dynamic property of a vehicle was found to influence the soil disturbed width of off-road vehicles. The accuracy of the DGPS used in measuring ground speed was not reported. Ehsani *et al.*[8] conducted a study to investigate the potential use of a Real-Time Kinematics (RTK) GPS receiver for seed location mapping. They reported that a wheel encoder had to be implemented to measure a planter ground speed as a radar gun and the RTK GPS did not provide sufficient speed measurement accuracy, especially at low ground speeds.

The literature review made for this study revealed that a lack of the knowledge in the accuracy of autonomous GPS system in ground speed measurement exists. Therefore, the overall goal of this study was to investigate, through a field study, the accuracy of a low-cost autonomous GPS receiver in vehicle ground speed measurement.

MATERIALS AND METHODS

A passenger vehicle was instrumented with a hand-held GPS receiver to provide GPS-derived ground speed data and a pulse transmitter to obtain vehicle's wheel speed. GPS-derived speed data was compared with the ground speed measurements based on wheel speed data (reference ground speed) and errors in GPS speed measurements were determined. The vehicle's speedometer was utilized as an initial indicator of the ground speeds targeted for this study which were 5, 10, 15, 20, 25, 30, 40 and 50 km h^{-1}. These ground speed values were chosen to cover the ground speed range required for most, if not all, agricultural operations.

GPS speed data acquisition: A hand-held Garmin eTrex Venture GPS receiver[9] operated in autonomous mode was used to provide GPS ground speed data. A study by Al-Gaadi[10] showed that this receiver maintained, on the average, a position determination accuracy of less than 2.10 m when the Selective Availability (S/A) was off. The same study revealed that the S/A, which is the biggest source of error in GPS data[3], was not in effect since at least October, 2003. Therefore, the GPS data for this test which was acquired on October, 2004 was assumed to be S/A error free. GPS speed data was acquired by internally programming the GPS receiver to output data in National Marine Electronic Association (NMEA) string format. Due to design and hardware limitations, it was found through preliminary testing that the receiver used in this study repeated a group of NMEA strings every 2 sec, therefore, it could output ground speed data, which was included in one of the strings, every two seconds as its only sampling rate. Since a sampling rate of ten seconds was decided to be used for this study, the sampling rate of the receiver was found to be sufficient. The GPS receiver was placed in the vehicle with a clear vision to the sky and connected to a lap top computer where collected raw data (NMEA strings) for the eight different test ground speeds could be monitored in real time and directly stored in a computer text file. A custom-written program was employed to filter the GPS raw data and pull the desired string (the RMC string) to another file that was imported into a work sheet for data analysis. The RMC data string was selected because it contained the ground speed data required for the purpose of this study. The RMC string containing file was further filtered to have the string repeated every ten seconds, instead of two seconds, where the records in between were removed. A total of 593 data points were contained in the last filtered work sheet GPS data file.

Reference ground speed data acquisition: The reference ground speed measurements were obtained by measuring the rotational velocity of the vehicle's wheel for the eight test ground speeds. Wheel velocity was measured by utilizing a pulse transmitter that sent a pulse every time a magnet fixed on one of the vehicle's wheels passed by it indicating one full rotation of the wheel. The pulse transmitter was fixed close to the tire where the horizontal distance between the transmitter and the magnet, when it passed by the transmitter, was about 1 cm. When passed by the transmitter, the magnet caused it to close the circuit providing a pulse. Pulses for ten seconds, which represented the number of wheel rotations occurred in ten seconds, were recorded for the eight test speeds by connecting the transmitter to an on-board CR23X micrologger, which was programmed to measure and record pulse data from the pulse transmitter at the specified sampling rate of ten seconds[11]. Data from the micrologger was downloaded to a computer text file which was imported into a work sheet for analysis. For each of the resulting 593 pulse data points, vehicle ground speed per ten seconds was calculated by multiplying the number of pulses by the known wheel circumference (2.07 m) divided by ten seconds. The ground speed in km h^{-1} was then calculated for each data point to match the unit of ground speed measurements produced by the GPS. Since the test was conducted on an asphalt surface, wheel slippage was negligible and pulses indicating numbers of wheel rotations were directly proportional to the forward vehicle ground speed.

At the beginning of the field data acquisition, the micrologger time was synchronized with the time on the

GPS receiver. Synchronization was conducted so that the data records from the GPS and the micrologger could be tagged using matching times, therefore, a time-specific data comparison could be achieved.

RESULTS AND DISCUSSION

GPS-derived ground speeds were tagged to reference ground speeds using record matching times. For each data point, the difference between GPS-derived speed and reference ground speed (error in GPS-derived speed) was calculated. For the whole test data set, the average error was found to be equal to 1.27 km h^{-1} (6.9%). An error of 0.51 km h^{-1} or less and an error of 5.54 km h^{-1} or less were associated with 50 and 95% of the data, respectively. High fluctuations of vehicle's speed greatly increased the error of GPS-derived speed. An error of -80.16% was produced due to a drop of vehicle's ground speed, based on reference ground speed measurements, from 18.65 to 11.19 km h^{-1} and an error of 47% was produced due to an increase of ground speed from 13.43 to 30.59 km h^{-1}. This leads to the conclusion that the GPS was not proportionally responsive to sudden big changes in ground speed.

For each of the eight ground speed data sets, a steady state analysis of GPS-derived ground speed measurement accuracy was conducted (Fig. 1). In this text, a steady state ground speed was defined as being the state where ground speed variation was limited to ±15% between two consequent data points. Therefore, the records which contained data points that caused variations exceeding the limit were removed from the reference ground speed data along with the corresponding GPS data records. This was accomplished to eliminate the effect of sudden high fluctuations of vehicle's ground speed on GPS-derived ground speed measurement accuracy. These fluctuations could not be avoided during the field test as they occurred when, for example, turning or passing another vehicle given the fact that the field test was conducted on public roads.

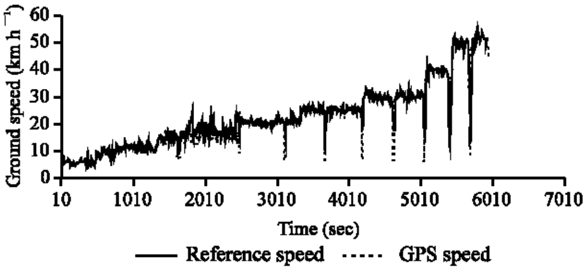

Fig. 1: GPS-derived and reference ground speed measurements

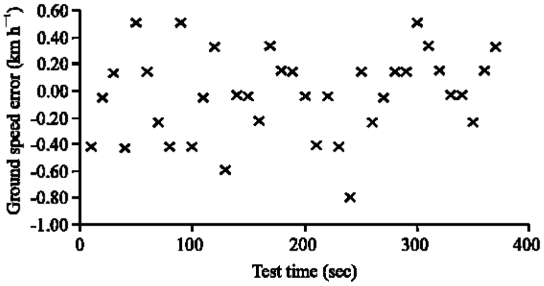

Fig. 2: Error in ground speed measurement for the 5 km h^{-1} data set

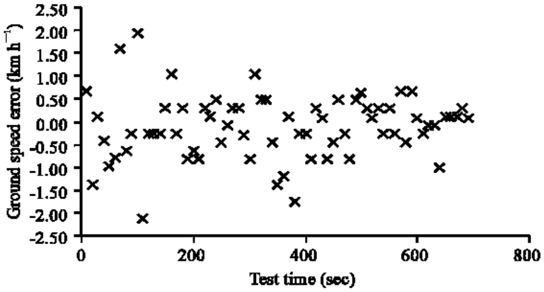

Fig. 3: Error in ground speed measurement for the 10 km h^{-1} data set

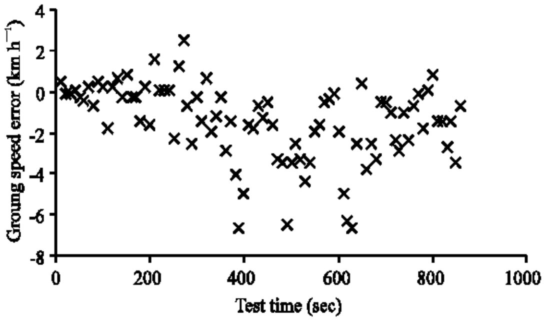

Fig. 4: Error in ground speed measurement for the 15 km h^{-1} data set

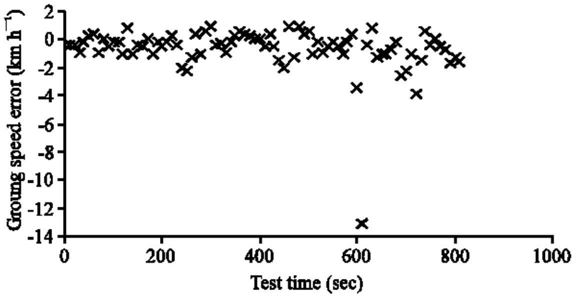

Fig. 5: Error in ground speed measurement for the 20 km h^{-1} data set

For all test speeds, the steady state analysis revealed that the GPS maintained, on the average, an error of less than 1 km h^{-1} except for the 15 km h^{-1} data set where the average error reached 1.72 km h^{-1}. Figure 2 to 9 show the errors in ground speed measurements produced by the GPS for the 5, 10, 15, 20, 25, 30, 40 and 50 km h^{-1} data sets, respectively, when compared with the reference ground speed measurements

The maximum error in GPS-derived speed measurement was found in the 20 km h^{-1} data set, where this error reached 13.11 km h^{-1} (Fig. 5 and Table 1). This individual extreme error was attributed to noise in the GPS hardware. For the 5 km h^{-1} data set, steady state analysis showed that the maximum error was 0.79 km h^{-1} (Fig. 2), however, 50 and 95% of the data points had an error of less than or equal to 0.22 and 0.51 km h^{-1}, respectively. The maximum error for the 10 km h^{-1} data set was 2.11 km h^{-1}, however, 50 and 95% of the data points had an error of less than or equal to 0.29 and 1.39 km h^{-1}, respectively (Fig. 3). A maximum error of 6.66 km h^{-1} was associated with the 15 km h^{-1} data set (Fig. 4), however, 50 and 95% of the data points had an error of less than or equal to 1.42 and 4.99 km h^{-1}, respectively. An extreme individual error of 13.11 km h^{-1} was found in the 20 km h^{-1} data set, however, 50 and 95% of the data had an error of less than or equal to 0.55 and 2.21 km h^{-1}, respectively. For the 25 km h^{-1} data set, a maximum error of 3.74 was produced (Fig. 6) and an error of less than or equal to 0.39 and 1.68 km h^{-1} was associated with 50 and 95% of the data points, respectively. The maximum errors for the 30, 40 and 50 km h^{-1} data sets were 5.20 km h^{-1} (Fig. 7), 3.11 km h^{-1} (Fig. 8) and 6.33 km h^{-1} (Fig. 9), respectively. For these data sets, 50% of the data points had an error of less than or equal to 0.43 km h^{-1} and 95% of these points had a maximum error of 1.85 km h^{-1}. Table 1 summarizes the

Table 1: Errors of GPS-derived ground speed in steady state

Targeted speed (km h^{-1})	Avg. reference speed (km h^{-1})	Avg. GPS-derived speed (km h^{-1})	Max. error (km h^{-1})	Avg. error (km h^{-1})	Max. error %	Avg. error%
5	5.61	5.58	0.79	0.25	11.81	4.44
10	10.55	10.43	2.11	0.54	20.27	5.23
15	16.50	14.92	6.66	1.72	32.02	9.92
20	20.70	20.00	13.11	0.94	67.57	4.55
25	25.07	25.03	3.74	0.65	20.04	2.67
30	29.82	29.54	5.20	0.62	19.92	2.13
40	39.83	39.53	3.11	0.59	7.43	1.50
50	50.56	50.23	6.33	0.79	12.29	1.57

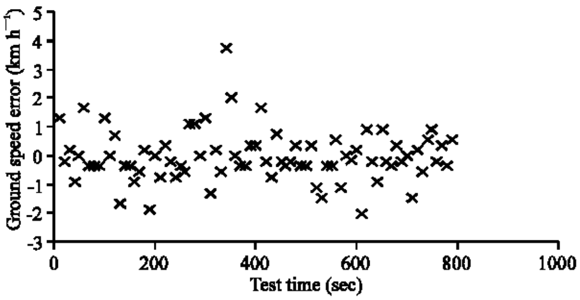

Fig. 6: Error in ground speed measurement for the 25 km h^{-1} data set

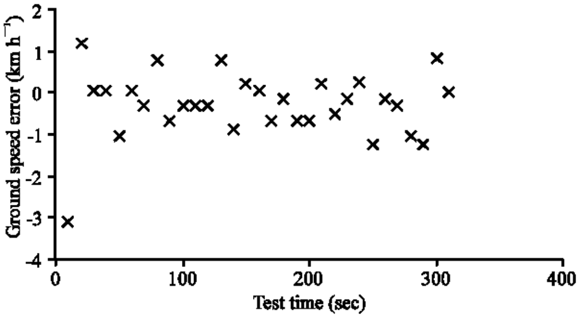

Fig. 8: Error in ground speed measurement for the 40 km h^{-1} data set

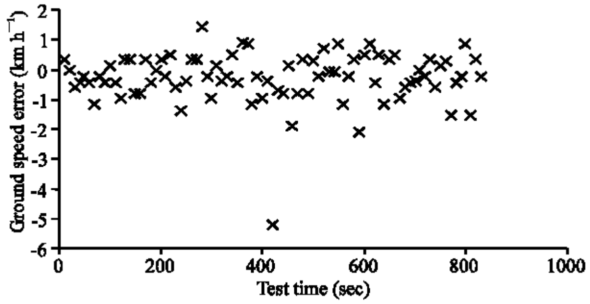

Fig. 7: Error in ground speed measurement for the 30 km h^{-1} data set

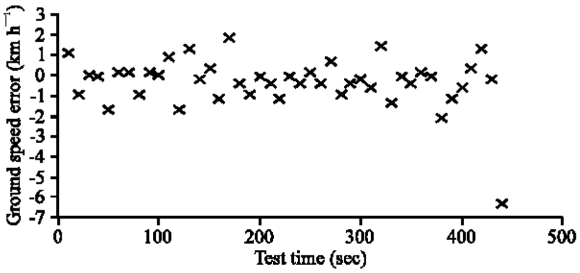

Fig. 9: Error in ground speed measurement for the 50 km h^{-1} data set

findings of the steady state analysis for the eight data sets.

For all test speeds, the GPS produced, in steady state, a ground speed measurement with an average error of no more than 5.23%, except for the 15 km h^{-1} data set where this error reached 9.92% (Table 1). It can also be seen that the magnitude of error was not related to the amount of ground speed. However, it was thought that the reference speed, based on which GPS-derived speed was evaluated, reflected the true ground speed of the vehicle as it was almost impossible to maintain constant vehicle ground speed under test field conditions.

CONCLUSIONS

The time-specific accuracy of an autonomous GPS receiver in measuring vehicle's ground speed was tested for eight different ground speeds. A pulse transmitter and a magnet were utilized to measure vehicle's wheel speed and a reference ground speed measurement was obtained. GPS-derived speeds were compared to the reference speed measurements and the following conclusions are drawn from the study:

- For all data points, the GPS produced, on the average, a ground speed measurement accuracy of 1.27 km h^{-1} (6.9%). A maximum error of 0.51 and 5.54 km h^{-1} were found to be associated with 50 and 95% of the data points, respectively.
- The GPS accuracy was found to be greatly degraded at sudden big changes of vehicle ground speed. An error -80.16% was produced due to a vehicle ground speed reduction from 18.65 to 11.19 km h^{-1} within 10 sec.
- To eliminate the effect of big sudden changes on GPS-derived speed accuracy, a steady state analysis was conducted for the eight test ground speeds. Results of the analysis revealed that the GPS maintained, on the average, an accuracy of less than 1 km h^{-1} for all test speeds, except for the 15 km h^{-1} data set where the average accuracy was 1.72 km h^{-1}. An average error of less than 5.3% was associated with all data sets, except for the 15 km h^{-1} data set where this error reached 9.92%.
- Results of the study revealed that the magnitude of error in tested GPS ground speed measurement was not proportional to the amount of vehicle ground speed.

REFERENCES

1. Hurn, J., 1989. GPS A Guide to the Next Utility. Sunnyvale, CA: Trimble Navigation Ltd.
2. Al-Gaadi, K.A., 1998. Integrating GIS and GPS into a spatially variable rate herbicide application system. Ph.D. Thesis, Fort Collins, CO. Colorado State University.
3. Hurn, J., 1993. Differential GPS Explained. Sunnyvale, CA: Trimble Navigation Ltd.
4. Al-Gaadi, K.A. and P.D. Ayers, 1994. Monitoring controller-based field sprayer performance. Applied Eng. Agric., 10: 205-208.
5. Guo, L.S. and Q. Zhang, 2002. Position estimate of off-road vehicle using a low-cost GPS and IMU. ASAE Paper No. 021157. St. Joseph, MI: ASAE.
6. Han, S., Q. Zhang, H. Noh and B. Shin. 2004. A dynamic performance evaluation method for DGPS receivers under linear parallel-tracking applications. Trans. ASAE, 47: 321-329.
7. Li, Q., P.D. Ayers and C. Wu. 2003, Soil and vegetation disturbance of tracked and wheeled off-road vehicles. ASAE Paper No. 031055. St. Joseph, MI: ASAE.
8. Ehsani, M.R., S.K. Upadhyaya and M.L. Mattson, 2004. Seed location mapping using RTK GPS. Trans. ASAE, 47: 909-914.
9. Garmin, C., 2001. Owner's Manual and Reference Guide for eTrex Venture GPS Receiver. (Garmin, C. and K.S. Olathe, Eds.).
10. Al-Gaadi, K.A., 2005. Testing the accuracy of an autonomous GPS when S/A is off and investigating its use in distance measurement in plain agricultural properties. Saudi J. Biol. Sci., 12 (In Press).
11. Annonymous, 2003. CR23X Micrologger Operator's Manual. Logan, UT: Campbell Scientific Inc.