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Field evaluation of two machine navigation systems for variable rate application

(Penilaian dua sistem pandu arah untuk mesin aplikasi kadar berubah-ubah)

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Key words: DGPS, beacon, satellite, variable rate application, precision farming

Abstract

Precision farming or spatially variable crop production (SVCP) aims to improve farm management efficiency by adjusting field/crop treatments to conditions existing at specific areas within fields. The implementation of map-based variable rate application in SVCP usually requires a navigation system for the application of production inputs. Positioning system requirements for application of farm inputs are different in terms of position resolution, reliability and dynamic performance. This paper describes the field performance of navigation tests of two DGPS receiver systems using the real-time differential correction signals from the US Coast Guard beacon signal and another from a commercial satellite-based wide area network. Tests were conducted in a citrus orchard located in the University of Florida, Gainesville, Florida. The dynamic repeatability performance of the two DGPS receivers was found not suitable as a stand alone system in the test site.

Introduction

Positioning system is a key component in precision farming or spatially variable crop production (SVCP). Variable rate application (VRA) has been used for field application of farm chemical inputs in spatially variable crop production. The implementation of VRA usually requires a navigation system in the application of production inputs. Positioning system requirements for the application of farm inputs are different in terms of position resolution, reliability and dynamic performance (Stafford 1999). In-field positioning systems, based primarily on global positioning system (GPS), have been used extensively in yield sampling of cereal crops for the development of yield maps. There are two broad classifications of VRA: sensor-based and map-based. In a sensor-based system, field information is gathered by the sensors as the equipment moves through the field and data is processed in real-time to generate desired application rates to control a variable rate applicator.

Navigation system is usually used in machinery guidance during field application. However, in the map-based system, field information is stored in a treatment map developed from sampling of various relevant field parameters and establishing a relationship among the parameters. During field application, machine field position determined from a geo-position sensor system such as a differential GPS (DGPS) receiver is used to read the desired

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application rate from a treatment map to control a variable rate applicator. Each method can be used in a complementary manner. Map-based application is the most common.

VRA of fertilizer or chemicals for the map-based system requires real-time computation of machine position because the application rate is adjusted during the field operation to match conditions at particular positions. VRA using real-time differential GPS (DGPS) system for machine navigation alone may not be sufficient due to the loss of real-time differential correction signals in poor environmental conditions such as tree obstructions or weak DGPS signal coverage areas. Field application of liquid fertilizer in VRA for a tree-based crop may require an integrated field machine navigation system using real-time DGPS and dead reckoning system.

Balsari et al. (1997) tested a dead-reckoning system for directional control of tractors in dry fields and paddy fields. They concluded the needs in using GPS for correcting compounded eventual errors of position due to lateral deviation of tractor in successive runs. Stoll and Kutzbach (1999) described a farm vehicle guidance system using a digitised field map guided by an integrated system using GPS coupled with other positioning devices based on a dead reckoning system. They suggested that the combination of GPS-dead reckoning is useful for operations in vineyards, orchards or forests.

Monson (1997) emphasized the importance of maintaining vehicle position with respect to the application map, as it is one of the most significant error sources in VRA. He then described a combination of GPS with an inertia navigation system which is capable of accurate differential equivalent machine positioning in areas of poor DGPS signal reception, such as under tree cover.

Other ground-based navigation systems studies have been reported: parallel swath in banana plantation using a combination of satellite based real time DGPS and light bar system (Molin and Ruiz1999), integrated radar-gyroscope-DGPS (real-time) system (Hellebrand and Beuche 1997), real-time DGPS with a light bar (Vetter 1995) and real-time DGPS with speed sensors and fluxgate compass sensor dead reckoning system (LeBars and Boffety 1997).

Chan (2000) and Chan et al. (2002) reported that GPS error is the most significant factor besides field boundary selection and mapping interpolation method affecting the accuracy of citrus yield mapping. Besides yield mapping, the accuracy of DGPS receiver in machine navigation was reported to be the most significant, in the absence of machine delay time, for variable rate application of liquid fertilizer for Florida citrus (Chan 2000).

The objective of this study was to study the suitability of two DGPS systems for machine navigation in VRA; the Goat system (GeoFocus Inc., Gainesville, FL) (*Plate 1*) and the Omnistar system (*Plate 2*) in a selected citrus farm. The Goat system has been used in citrus yield data collection while the Omnistar system is a stand-alone DGPS unit. The dynamic repeatability accuracy (field navigation) of both the Goat and the Omnistar DGPS systems were evaluated.

There are several studies on error and accuracy of GPS used in VRA. It is important to understand the GPS signal characteristics and sources of GPS errors in the evaluation of navigation system based on GPS.

The quality of GPS positioning for machine navigation system used in VRA depends on: length of the baseline for relative positioning, atmospheric conditions, GPS signal (phase or code), number of frequencies capable of being received by the receiver, processing model of the receiver, local environmental condition, GPS antenna type, static or kinematic data collection methods used, and differential signal correction in real-time or post processing (Barnes and Cross 1998). Sources of errors

Plate 1. Goat DGPS system

Plate 2. Omnistar DGPS system

in navigation systems include selective availability, atmospheric (ionosphere and troposphere), satellite clock and emphemeris, multi-path and receiver noise.

Real-time differential correction has been used to improve position resolution of uncorrected GPS signals. There are many methods in transmitting real time differential correction signals such as US Coast Guard beacon RTCM SC-104, local base AM, FM sub carrier, and wide area based satellite.

Larsen et al. (1988) investigated requirements of a real-time DGPS field navigation system for field application. They described an operator-assisted navigation using pre-determined machine path shown on the operator control graphic screen.

Spruce et al. (1993) used GPS to track a site preparation skidder and a small farm tractor under both forest canopy and open sky conditions using a 6-channel hand-held GPS and using post-processing method for differential correction. They concluded that machine navigation was satisfactory in open sky conditions while forest canopy significantly degraded GPS signal quality. They suggested further investigation into combination GPS-dead-reckoning navigation systems.

Hellebrand and Beuche (1997) field tested a machine guidance system using a real-time DGPS integrated with a piezoelectric vibrating gyroscope dead-reckoning system. Differential correction was via a FM receiver. They concluded that the accuracy of positioning systems for agricultural applications should be better than 3 m using real-time DGPS. However, they reported that real-time DGPS is not always reliable due to satellite availability and electromagnetic wave transmission disturbances. Dead reckoning by an independent location system is said to improve the machine guidance performance.

Molin and Ruiz (1999) tested a SATLOC SwathStar light bar parallel swathing system in a banana plantation using a real-time DGPS system with an Omnistar receiver fitted to a tractor. The sampling frequency of Omnistar DGPS receiver was not mentioned. Tests were conducted at 7.92 and 13.50 km/h over a 200-m long test path. Three groups of 40 points along the 200-m test path were sampled for each pass and analysed for cross-track error. Average error of 1.65 m (50 percentile) and 2.5 m (90 percentile) were reported at a tractor speed of 7.92 km/h and 1.75 m (50 percentile) and 2.10 m (90 percentile) for a speed of 13.50 km/h.

Materials and methods

The Goat (GeoFocus Inc., Gainesville, FL) system is a commercial yield monitor, model number 1002-103, fitted with an OEM Trimble (Trimble, Sunnyvale, CA) Lassen-SK8 (8-channel, L1-band, C/A code) GPS board connected to a compact active micropatch GPS antenna via a 5-m cable. It was also fitted with a CSI (CSI Inc., Calgary, AB) SBX-2 DGPS board and a CSI MBA-3 beacon whip antenna capable of receiving real-time RTCM SC-104 differential correction signals from the US Coast Guard. The available signals were 312 kHz from Egmont Key, FL and 289 kHz from Cape Canaveral, FL. Recorded positional data from the Goat System in the Trimble TSIP format were downloaded via a key card and read by a key card reader, connected to a personal computer. Sampling interval of the Goat unit was set at 0.1 s.

The Omnistar system used an 8-channel, L1-band, C/A code Omnistar (Omnistar Inc., Houston, TX) model OS7000 DGPS receiver capable of receiving real-time Omnistar satellite-based differential correction signals from its SPACENET 3 satellite transmitting at C-band (3750/4250 MHz). Data output from the Omnistar unit was connected with a RS-232 serial cable to a notebook computer at 4800-baud rate. The data output is in NMEA 0183 format showing data in position, and time at 1 Hz.

Site

Clark and Worley (1994) studied the deviation of machine path, indicated by a post-processed differential GPS signal, from a surveyed field path. A relatively flat field plot planted with about 4 m height citrus trees, with 4.57 m within row and 6.10 m between row spacing, located at the University of Florida, Gainesville, FL, was selected for these tests. A rectangular surveyed path of 173.98 m (side A) x 61.57 m (side B) x 173.56 m (side C) x 61.58 m (side D) was marked out using wooden stakes and displayed in the field by connected strings tied to those wooden stakes (*Figure 1*). Total length of the surveyed path was 470.69 m.

Field tests

The Goat DGPS system was tested on 10 March 1999 while the Omnistar DGPS system was tested on 16 March 1999. A total of eight and ten test runs were conducted for the Goat and Omnistar DGPS respectively. During these field tests, the antenna (Goat unit) or DGPS receiver (Omnistar unit) was mounted on the top of the vehicle at the middle section of a small Kawasaki 4-wheel farm transporter. A 1.5 m pole was fitted in front of the vehicle, at the middle section of the driver cab and aligned with the DGPS receiver/antenna, to serve as a visual guidance marker for the operator to follow the surveyed machine path displayed by the nylon string. An experienced operator drove the small transporter at an average speed of 3 km/h between two rows of citrus tree. Data recording of the Goat unit was performed manually by pressing the push button for each DGPS signal indicated on the Goat display screen while the real-time

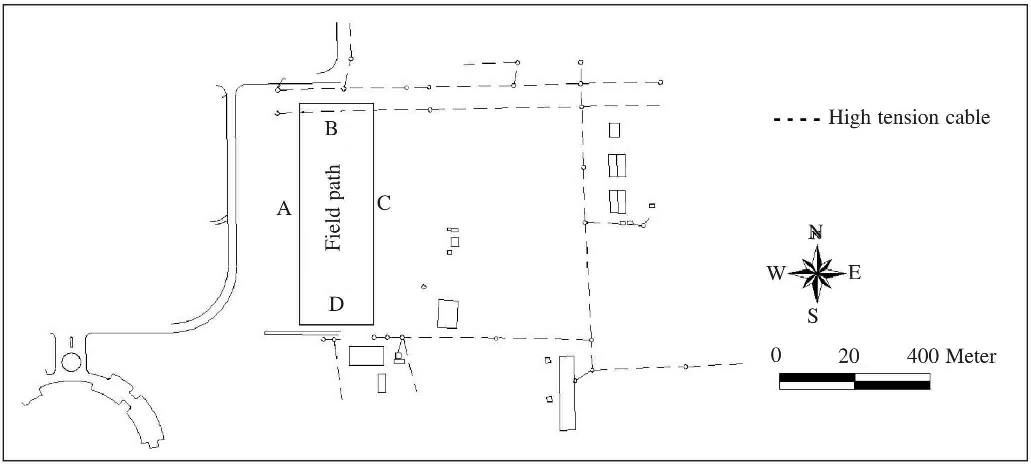

Figure 1. Layout of a surveyed rectangular path in a citrus field for machine navigation studies

Omnistar unit output was continuously stored into a laptop computer via a RS-232 serial cable.

Data analysis

Monson (1997) developed a methodology for quantifying the capabilities of various GPS and DGPS based systems for dry fertilizer application. He described a measurement method for GPS system latency in quantifying the dynamic error of a GPS receiver used in field navigation. Three types of accuracy of location data were discussed: static position accuracy, static multiple position accuracy and dynamic accuracy. Dynamic accuracy of GPS/DGPS equipment was considered important for navigation during variable rate application. Similarly, Saunders et al. (1996) reported a methodology for evaluating DGPS used in navigation systems, which included dynamic stability, dynamic repeatability and precision tests. The dynamic repeatability of the Goat system and the Omnistar system were tested using methods similar to those described in Saunders et al. (1996).

ArcView version 3.1 (Environmental Systems Research Institute (ESRI), Redlands, CA.) computer program was used to visually observe all the actual machine paths travelled. Actual deviation of machine path indicated by the real-time DGPS data point from the surveyed path (cross-track error) was used to quantify the accuracy of the navigation system. Measurement of maximum cross-track error and percentage of real-time DGPS position data for each round of test was visually recorded using the ArcView computer program using its measuring tools.

Results and discussion

Large deviations from surveyed path in some test runs for both the Goat DGPS and Omnistar DGPS system were observed. *Table 1* summarizes the dynamic repeatability performance of the Goat DGPS unit when driving five rounds in clockwise and three rounds in counter-clockwise direction following closely to the surveyed rectangular path. The highest percentage of about 44% estimated real-time DGPS data point was observed in test run number 2 in the clockwise direction. However, a high maximum cross-track error of 82 m was observed in test run 2 along machine path A. It is believed that the presence of a 69 kV high-tension cable above machine path B could cause the loss of real-time signal as no real-time DGPS signal was detected by the Goat unit throughout all the test runs.

Overall test run number 1 yielded the best results with maximum cross-track error ranged from 3.85 m to 8.85 m and an overall 39% of estimated real-time DGPS data point. *Figure 2* shows some examples of the dynamic repeatability performance of the Goat unit when driving five rounds in clockwise and three rounds in counter-clockwise direction following closely to the surveyed rectangular path.

VRA field application using the Goat navigation system was inadequate as indicated by its low overall percentage of real-time DGPS signal couples with high maximum cross-track errors (*Table 1*). The possibility of integrating Goat real-time DGPS with a dead-reckoning system while making use of fixed between-tree-row distance should be explored.

Figure 3 shows four examples of the dynamic repeatability performance of the Omnistar navigation system when driving five rounds in both clockwise and counter-clockwise directions following closely to the surveyed field path. Generally, the percentage of real-time DGPS signal detected by the Omnistar receiver was low, where only six test runs out of 10 were successful. Furthermore, the overall percentage of real-time DGPS signal position data was low compared with the Goat unit. The presence of 69 kV high-tension cable also caused the lost of real-time DGPS signals for all test runs except a small section in test run 2.

Generally, the magnitude of maximum cross-track error of the Omnistar navigation

Table 1. Summary of dynamic repeatability performance for GOAT DGPS

Test No./ Direction	Machine path	Max. cross-track error (m)	Percentage of real-time DGPS point (%)*
1/clockwise	A	8.85	38
	B	na	0
	C	3.85	52
	D	6.06	45
	Overall	–	39
2/clockwise	A	82.00	21
	B	na	0
	C	7.07	68
	D	10.42	85
	Overall	–	44
3/clockwise	A	4.97	61
	B	na	0
	C	1.96	28
	D	6.01	73
	Overall	–	42
4/clockwise	A	4.89	11
	B	- na -	0
	C	19.07	29
	D	7.25	58
	Overall	–	22
5/clockwise	A	3.90	25
	B	na	0
	C	26.93	34
	D	4.61	34
	Overall	–	26
6/anticlockwise	A	3.86	12
	B	na	0
	C	27.91	32
	D	5.77	54
	Overall	–	24
7/anticlockwise	A	2.63	15
	B	na	0
	C	4.50	24
	D	2.44	18
	Overall	–	17
8/anticlockwise	A	na	0
	B	na	0
	C	7.91	26
	D	4.11	50
	Overall	–	16

Estimated total number of data point for path A (173.98 m), B (61.57 m), C (173.56 m), and D (61.58 m) are 209, 74, 208 and 74 respectively
na = No data

Table 2. Summary of dynamic repeatability performance for Omnistar DGPS

Test No./ Direction	Machine path	Max. cross-P track error (m)	ercentage of real-time DGPS point (%)*
1/clockwise	A, B, C, D	na	na
2/clockwise	A	na	0
	B	4.21	23
	C	6.45	31
	D	10.09	78
	Overall	–	25
3/clockwise	A	4.48	23
	B	na	0
	C	4.64	17
	D	na	0
	Overall	–	15
4/clockwise	A	12.98	12
	B	na	0
	C	3.96	25
	D	na	0
	Overall	–	13
5/clockwise	A	5.05	18
	B	na	0
	C	na	0
	D	na	0
	Overall	–	7
6/anticlockwise	A	na	0
	B	na	0
	C	3.09	19
	D	na	0
	Overall	–	7
7/anticlockwise	A, B, C, D	na	na
8/anticlockwise	A, B, C, D	na	na
9/anticlockwise	A	na	0
	B	na	0
	C	1.88	37
	D	na	0
	Overall	–	13
10/anticlockwise	A, B, C, D	na	na

Estimated total number of second for path A (173.98 m), B (61.57 m), C (173.56 m), and D (61.58 m) are 209, 74, 208 and 74 respectively
na = No data

system was lower than the Goat unit with the highest of 12.98 m (*Table 2*) being observed in machine path A during test run 4 (*Figure 4*). These results suggested the inadequacy of the Omnistar real-time DGPS navigation system for machine navigation in VRA. A reliable real-time DGPS machine guidance system should provide a consistently low cross-track error. The possibility of integrating Omnistar real-time DGPS with a dead-reckoning system while making use of fixed between-tree-row distance should be explored.

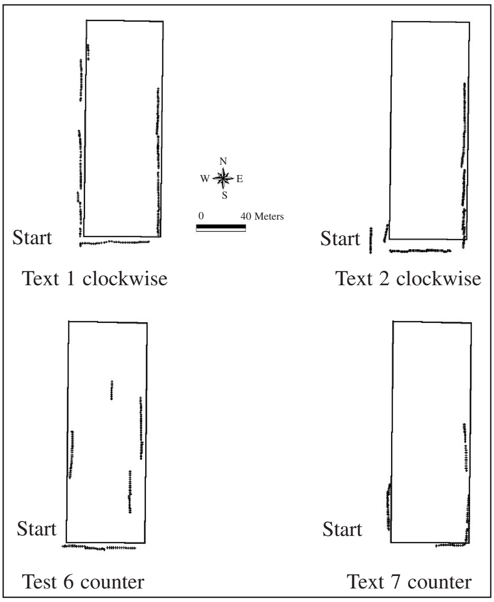

Figure 2. Examples of four actual machine path over the surveyed rectangular path in a citrus field using the Goat real-time DGPS navigation system

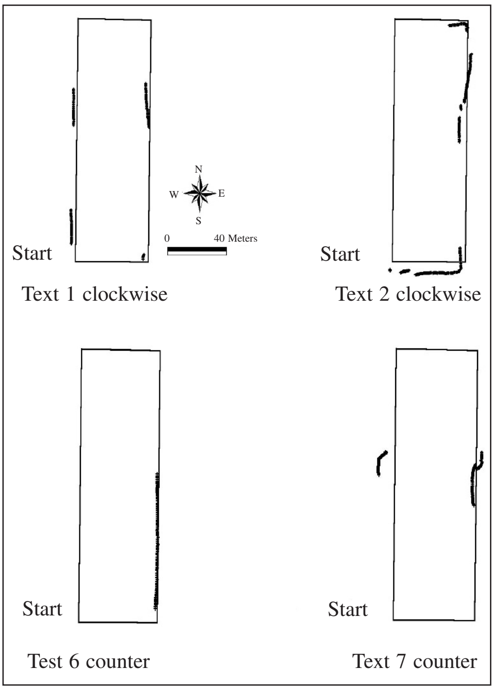

Figure 3. Examples of four test runs showing actual machine path over the surveyed rectangular path in a citrus field using the Omnistar real-time DGPS navigation system

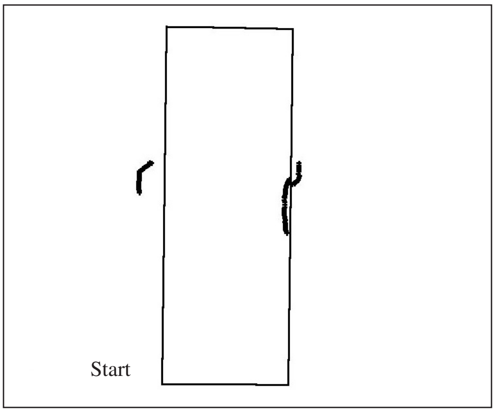

Figure 4. Examples of test run 4 showing actual machine path over the surveyed rectangular path in a citrus field using the Omnistar real-time DGPS navigation system

Conclusion

Using only the Goat DGPS or Omnistar DGPS receiver for real-time machine guidance in a tree-based VRA was not good enough. This was reflected in a very high percentage of DGPS positional data recorded in path A, B, C and D coupled with a high cross-track error. The presence of factors such as high-tension electricity may degrade the DGPS signal. The possibility of integrating the real-time DGPS receiver with a dead-reckoning system, as reported in other studies, should be explored.

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Abstrak

Tujuan utama pertanian tepat atau pengeluaran tanaman secara spatial berubah (SVCP) adalah untuk meningkatkan kecekapan pengurusan dengan amalan aplikasi input ladang/tanaman yang tepat dan sesuai dengan keadaan di ladang. Implimentasi aplikasi sistem input pertanian secara berubah-ubah yang berasaskan peta dalam SVCP memerlukan satu sistem pandu arah. Keperluan sistem kedudukan mesin di ladang untuk aplikasi input pertanian adalah berlainan dari segi resolusi kedudukan, kebolehharapan dan kecekapan dinamik. Keupayaan dua sistem pandu arah global jenis kebezaan (DGPS) yang menggunakan isyarat kebezaan jenis masa nyata dari matarah US Coast Guard dan isyarat dari sistem komersial sistem satelit kawasan-luas telah dikaji. Kajian kedua-dua sistem dilakukan di ladang limau di Univesiti Florida, Gainesville. Keputusan kajian menunjukan kecekapaan ulangan dinamik kedua-dua sistem satelit adalah tidak memuaskan.

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