Performance of two differential global positioning system (DGPS) receivers for precision agriculture
(Prestasi dua penerima sistem penempatan global kebezaan (DGPS) untuk pertanian tepat)

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Key words: precision agriculture, GPS, accuracy, differential GPS signal

Abstract
The implementation of spatially variable crop production (SVCP) requires an in-field positioning system for mapping and/or sensing of field attributes. Positioning system requirements for mapping and/or sensing are different in terms of position resolution, reliability and dynamic performance. This paper describes the accuracy of two differential global positioning system (DGPS) receivers for data collection in SVCP. Results indicated differential signal is important for high position resolution. The DGPS receiver using wide area satellite based differential signal performed better than the beacon-based DGPS signal.

Introduction
GPS in precision agriculture

Spatially variable crop production (SVCP), a concept practised in precision agriculture, requires an in-field positioning system for mapping and/or sensing of field attributes. Positioning system requirements for mapping and/or sensing are different in terms of position resolution, reliability and dynamic performance (Stafford 1999).

Global Positioning System (GPS) allows precise positioning measurement on earth. The GPS was developed by the U.S. Department of Defense as a military navigation system. GPS uses a constellation of more than 24 satellites orbiting earth. It works by having a receiver (either hand-held or attached to a utility vehicle) that accepts radio signals from the satellites. The receiver then computes its field position, in terms of

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a longitude and latitude, using data received from the satellites. Currently, the GPS receiver calculates inaccurate positioning data due to several environmental factors. Accurate positioning measurement is a key to SVCP. GPS allows measurement of the location of crop areas, trees, irrigation heads, drainage lines and other important field information.

In-field positioning systems, based primarily on GPS, have been used extensively in yield sampling of cereal crops for the development of yield maps. Crop harvested by a combine harvester fitted with a yield monitor and GPS receiver is used. Usually the mass or volume of grain harvested per unit area, by location, within a field is recorded. Yield maps can be developed using the collected yield data followed by data interpolation.

Chan (2000) and Chan et al. (2002) reported that GPS error plays a very important role in the accuracy of citrus yield mapping in which the GPS error is the most significant factor besides field boundary selection and mapping interpolation method. An error model was developed relating the three factors. The choice of GPS receiver’s accuracy level should be considered in its adoption for precision agriculture application. It is also important to understand the GPS signal characteristics and sources of GPS error in the evaluation of in-field GPS positioning system accuracy.

**GPS signal characteristics and sources of error**

Barnes and Cross (1998) described a range of factors affecting the quality of GPS positioning: whether positioning is absolute or relative, 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.

Accuracy in positioning system is dynamic and can be affected by both spatial and temporal factors. Sources of error in in-field positioning systems include selective availability, atmospheric (ionosphere and troposphere), satellite clock and ephemeris, multi-path and receiver noise. In May 2000, the United States Government had removed the signal interference to GPS due to selective availability. This has provided a better position resolution than before for in-field positioning system using GPS receiver.

Differential correction for GPS (DGPS) has been used to improve position resolution either through post or real time processing of uncorrected GPS signals. DGPS has a better position accuracy than the GPS receiver. Post processing of differential signals can be done either using downloaded base station files from various web sites or from the GPS differential signal service providers. There are many methods in transmitting real time differential correction signals such as the U.S. Coast Guard beacon RTCM SC-104, local base AM, FM sub-carrier, and wide area satellite based. The beacon signal from the coast guard and the wide area satellite based are the most common. The beacon signal is usually free and a subscription fee is usually required for the satellite based differential correction signal.

Rupert and Clark (1994) studied the accuracy of a L1 band, Coarse and Acquisition (C/A) code GPS receiver using post processing of differential correction signals for point data collection. They also described the importance of precision dilution of precision (PDOP) as a major contributing factor in positioning error.

Mack (1997) reported the static positioning performance of a high quality and a standard GPS receiver over a 24-hour period at a precisely known point. He described a high quality receiver as having more channels, using advanced signal observation techniques, and makes better use of carrier and doppler observations. He suggested the use of a wide area satellite
based differential correction signal system for coverage over a large area farm.

Navstar (Anon. 1995) characterized the behaviour of GPS position solution error as changing considerably over time at any given location. A 24-hour sampling interval is used in their accuracy performance standard. Saunders et al. (1996) also reported a methodology for evaluating DGPS receivers, which included static accuracy, static stability, dynamic stability, dynamic repeatability and precision tests.

This paper focuses on the GPS receiver’s accuracy for mapping application in precision agriculture. The objective of this study was to measure the static predictable accuracy of two types of DGPS receiver; an on-board DGPS receiver with the differential correction signals from the U.S. Coast Guard and another DGPS receiver systems with the wide area satellite based differential correction signals for in-field data collection in SVCP management.

Materials and methods

DGPS receiver

Two DGPS receivers were tested in this study; the Goat system (GeoFocus Inc., Gainesville, FL) (Plate 1) and the Omnistar (Omnistar Inc., Houston, TX) system (Plate 2). The Goat system has been used in citrus yield data collection while the Omnistar system is a stand-alone DGPS unit.

The Goat 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 U.S. 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
Trимбл TSIP format were downloaded from a personal computer via a key card and read by a key card reader. Sampling interval of the Goat unit was set at 0.1 s. An ATC (ATC, Lancaster, PA) 422 flip-flop timer was used in continuous data collection over a 24-hour period.

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 transferred to a notebook computer at 4800 baud rate through a RS-232 serial port. The data output is in NMEA 0183 format showing data in position, PDOP and time at 1 Hz.

The predictable static accuracy of the Goat system and the Omnistar system were tested using methods similar to those described in Saunders et al. (1996). The effect of differential GPS signal for the Goat system was evaluated over a 24-hour period by physically disconnecting the DGPS cable connection to the Goat yield monitor during data collection.

**Predictable static accuracy tests**

For the Goat system, GPS and DGPS antennae were placed at a fixed position on the roof of the Geoplan Center at the University of Florida in Gainesville, FL, at latitude 29° 38.854914' N and longitude 82° 20.498121' W, 2.02 m away from the Geoplan Center base station. The location of the base station is at latitude 29° 38.854779' N and longitude 82° 20.499361' W. Position data recording was set at a 1-minute interval using the ATC 422 timer and collected over a 24-hour period. The weather conditions during the test were calm and clear sky with minimal cloud cover.

In the Omnistar system, the DGPS receiver was placed in another nearby location on the roof but with a fixed location at latitude 29° 38.854779' N and longitude 82° 20.498121' W, 2.00 m away from the Geoplan Center base station. Positional data was recorded using the default setting at 1 Hz and collected over a 24-hour period on another day. Similar weather conditions were experienced as in the day of the Goat system test.

**Data analysis**

Circular error probable (CEP), root means square (RMS), twice the distance RMS (2dRMS), horizontal 95-percentile (R95), mean, etc. have been used to define GPS spatial accuracy (Diggelen 1998). Anon. (1995) described a direct method using 95-percentile Euclidean horizontal error of GPS static position collected over a 24-hour period to quantify the static position resolution of a GPS receiver. They also described the data distribution, coverage, availability and reliability of GPS data. Saunders et al. (1996) also quoted the 95-percentile horizontal error and Euclidean horizontal error about the mean of all data point. Meanwhile, Huff (1997), compared the performance of nine GPS receivers using their 24-hour data on horizontal dilution of precision (HDOP), easting error, northing error and number of satellites. Mean position and standard deviation were used to quantify their performance. An integrated method of analysis based on Saunders et al. (1996), Anon. (1995) and Huff (1997) was used in this study which consider data distribution and satellite signals (HDOP, satellite number). The 95-percentile Euclidean horizontal error was used to quantify the static predictable horizontal error of each system.

**Results and discussion**

**Goat system**

The real time Goat system DGPS signals data collected from 5–6 March 1999 over a 24-hour period was analysed. A total of 574 (40% of 1440) static position data were collected where 549 (96% of 574) of the data were real time DGPS and 25 (4% of 574) were non-differential. These missing
866 static positional records could be due to the irregular problem in the internal electronic circuit to trigger the automatic data collection set up using the ATC 422 timer with the Goat unit. There were two major intervals of missing data: 1 hour, and 12 hours and 20 minutes (between 5 March 1999 11:50 p.m. and 6 March 1999 12:10 p.m.) as the automatic triggering of data collection was believed to be not functioning. However, data recording was automatically working again for the last three minutes of data collection before recording was finally stopped. It was observed that these missing data occurred immediately after non-real time DGPS data were recorded.

Latitude and longitude error distribution of the selected 549 DGPS data showed a Gaussian pattern with a narrow spread indicating a high position resolution in both the latitudinal and longitudinal direction (Figure 1). Figure 2 shows the scatter distribution of 574 position records for latitude/longitude position and latitude/longitude error of both real time DGPS and GPS data. Obviously, DGPS position data had a better position resolution than the GPS data. There were two outlier DGPS points measured by the Goat real time DGPS unit with latitude/longitude error at $-18.38\,\text{m}$/$-16.24\,\text{m}$ and $44.22\,\text{m}$/$13.93\,\text{m}$ from the Goat surveyed position. These two points were recorded at 2:56 a.m. and 4:36 a.m. 6 March 1999 where the receiver detected only four satellites. Further analysis on the influence of PDOP and HDOP suggested good positional satellite geometry recorded by the receiver. The reason for many non-differential readings on 6 March 1999 is believed to be caused by poor reception of the U.S. Coast Guard RTCM SC-104 signal as the Gainesville location is on the outer fringe area of this RTCM SC-104 signal coverage, being 230 km from the transmission site.

**Omnistar system**

A total number of 86 399 position records, sampled at 1 s interval, for the Omnistar real time DGPS were collected over a 24-hour period from 25–26 March 1999. A final set of 567 DGPS records were selected from these records for further analysis on its position resolution. Latitude and longitude error distribution showed a Gaussian pattern with a similar small spread of position resolution (Figure 3). Scatter distribution of the latitude and longitude DGPS position indicated an oval data distribution (Figure 4). HDOP values recorded by the receiver were good coupled with a high number of satellites at around eight most of the time. There was no significant outlier recorded in the Omnistar DGPS as compared to the Goat DGPS unit.

The static position resolution for the two systems were noted in the 95-percentile,
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Figure 2. Scatter distribution of latitude and longitude static positional data of a Goat unit real time DGPS receiver over a 13-hour period (black dots)

\[ R^2 = 0.89 \]

\[ R^2 = 0.94 \]

Figure 3. Distribution of latitude and longitude error of static positional data over a 24-hour period for the Omnistar real time DGPS receiver
mean difference, standard deviation and
dRMS error where the Omnistar system has
the lowest deviation (0.756 m) and best
position resolution (2.493 m at 95-
percentile) (Table 1). These results suggested
the importance of DGPS signal in position
resolution where the absence of differential
correction can degrade the position
resolution to 60.463 m (95-percentile) for
the Goat unit. Furthermore, static position
resolution results obtained from these tests
can also be used to compare with those as
specified in the manufacturer’s catalogue
since DGPS position resolution is dynamic
and dependent on user’s location.

Conclusion
Real time DGPS signal is important for
static positioning as indicated by the higher
position resolution for both the Goat and
Omnistar receivers than the Goat non-
differential signal. The Goat and Omnistar
units had a horizontal 95-percentile error of
4.017 m and 2.493 m (R95) respectively.
The standard deviation of position resolution
for the Omnistar unit (0.756 m) was lower
than the Goat unit (2.317 m).

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Disclaimer
The mentions of commercial products are
for information purposes only and do not
constitute an endorsement.
Table 1. Comparison of GPS predictable static position resolution

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Receiver/Differential method</th>
<th>Dimension</th>
<th>Sample size</th>
<th>Mean difference (m)²</th>
<th>Mean difference of QR5 (m)²</th>
<th>Standard deviation or RMS error (m)²</th>
<th>Standard deviation in Euclidean distance computed from northing and easting (m)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Goat/Yes/Nothing</td>
<td>Easting</td>
<td>499</td>
<td>1.721</td>
<td>1.721</td>
<td>0.242</td>
<td>0.242</td>
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<tr>
<td></td>
<td></td>
<td>Horizontal</td>
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<td>2.322</td>
<td>2.322</td>
<td>2.891</td>
<td>2.891</td>
</tr>
<tr>
<td>2</td>
<td>Omnistar/Yes/Nothing</td>
<td>Easting</td>
<td>567</td>
<td>0.204</td>
<td>0.204</td>
<td>0.948</td>
<td>0.948</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horizontal</td>
<td></td>
<td>2.493</td>
<td>2.493</td>
<td>2.891</td>
<td>2.891</td>
</tr>
</tbody>
</table>

*Computed from rank and percentile of sample population for error of each computed position from a known base reference point.*

1. Difference between GPS/DGPS mean position and position computed from a known base reference point.
2. Standard deviation with reference to the mean of measured GPS/DGPS.
3. Euclidean distance computed from northing and easting.

References


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