Research Article/*Araştırma Makalesi*

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AKDENİZ ÜNİVERSİTESİ
ZİRAAT FAKÜLTESİ DERGİSİ
(2012) 25(2): 85-92

Linearity comparison of single and dual frequency GPS receivers under dynamic conditions

Dinamik şartlar altında tek ve çift frekanslı GPS alıcılarının doğrusallık karşılaştırması

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ARTICLE INFO

Received 19 March 2012
Received in revised form 02 July 2012
Accepted 09 July 2012

***Keywords*:**

Precision agriculture
GPS
Accuracy

ABSTRACT

GPS (Global Positioning System) receivers are one of the main elements for Precision Agriculture applications. The level of desired accuracy in applications varies greatly from application to application. Commercially available GPS receivers provide accuracy anywhere from1 meter to 3 meters. This accuracy range can be up to a centimeter with corrective signals such as real time kinematic or CORS (Continuously Operating Reference Station) network. The objective of this study was to compare the linear accuracy of single (Garmin Etrex Legend) and dual – frequency (Magellan ProMark 500) GPS receivers. The receivers were placed about 0.2 m apart from each other on top of an agricultural tractor. The tractor was steered at different speeds as a straight line to collect coordinate data. To compare receivers, the collected data were separately mapped for each receiver using the ARCGIS 9.3 software. So, standard deviations, standard errors of cross track error (XTE) and horizontal accuracy (DRMS) values of straight lines for each receiver were analyzed. Also, we investigated the effects of different speeds to horizontal accuracy. In conclusion, the results indicated that the Magellan Promark 500 yields more horizontal accuracy than the Garmin Etrex Legand. Also, different speeds did not have significant influence on the horizontal accuracy.

MAKALE BİLGİSİ

Alınış tarihi 19 Mart 2012
Düzeltilme tarihi 02 Temmuz 2012
Kabul tarihi 09 Temmuz 2012

***Anahtar Kelimeler*:**

Hassas tarım
GPS
Hassasiyet

ÖZ

GPS alıcıları hassas tarım uygulamaları için kullanılan temel elemanlardan biridir. Uygulamalarda istenen hassasiyet düzeyi, büyük ölçüde uygulamadan uygulamaya farklılık göstermektedir. Ticari olarak kullanılmakta olan GPS alıcıları yaklaşık olarak 1 ile 3 m arasında hassasiyet değerine sahiptirler. Bu hassasiyet sınırları, RTK (Real Time Kinematic) ve CORS ağı gibi düzeltme sinyalleri yardımı ile santimetre altı seviyeye indirgenebilmektedir. Bu bağlamda, çalışmanın amacı tek (Garmin Etrex Legand) ve çift frekanslı (Magellan ProMark 500) GPS alıcılarının hassasiyet değerlerinin karşılaştırılmasıdır. İki alıcı 20 cm aralıklara aynı hizada traktörün üzerine yerleştirilmiştir. Koordinat verilerinin toplanması için traktör, farklı hızlarda, doğrusal hatlar oluşturulacak şekilde ilerletilmiştir. Karşılaştırma işleminin yapılabilmesi için her bir alıcıya ait GPS verileri ARCGIS 9.3 yazılımı kullanılarak haritalandırılmıştır. Doğrusal hatlar üzerindeki doğrultudan sapma hatalarının (XTE) standart sapma ve standart hata değerleri ile yatay hassasiyet (DRMS) değerleri analiz edilmiştir. Ayrıca, farklı ilerleme hızlarının yatay hassasiyet üzerindeki etkileri araştırılmıştır. Sonuç olarak, Magellan Promark 500 alıcısının Garmin Etrex Legand alıcısından daha hassas olduğu belirlenmiştir. Ayrıca, farklı ilerleme hızlarının yatay hassasiyet üzerinde önemli bir etkisinin olmadığı saptanmıştır.

1. Introduction

Determination of the variability of temporal, spatial and predictive on the field is important for precision agriculture applications. If the agricultural activity carries out the right thing, at the right place, at the right time, precision agriculture can be beneficial. In precision agriculture applications, determination of the geographic position of operating machines is essential. In this sense, various positioning method, including mechanical, optical, radio, and ultrasonic techniques, have been investigated since the 1991 (Tillett 1991). Since the mid-1990s, the Global Positioning System (GPS) has become fully operational and commercially available, and GPS receivers have been widely used as position sensors in site-specific crop management (Han et al. 2004).

The Navstar Global Positioning System (GPS) is a satellite-based radio navigation system developed and operated by the U.S. Department of Defense that allows users to determine three-dimensional position and velocity anywhere in the world with a high degree of accuracy (Tyler 1992). GPS satellites broadcast own data such as location, time, system status and the ionosphere delay with the two different carrier frequencies (L1 – 1575.42 and L2 – 1227.60 Mhz) and the low power (20 – 50 W). GPS satellites transmit both a standard C/A (Coarse acquisition) code and a precise P code (restricted to U.S. government use) on each of two frequencies. System designers have developed navigation and positioning solutions based on processing the C/A code, the P code, and/or the underlying carrier wave from one or both frequencies (Borgelt et al. 1996).

A GPS receiver's job is to locate four or more satellites, figure out the distance to each, and use this information to deduce its own location. This operation is based on a simple mathematical principle called trilateration (Blewitt 1997). There are two measuring methods for GPS receivers to determine the position: pseudo range measurement and carrier phase measurement. The pseudo-range positioning technique compares the coded signal transmitted from the satellites with an exact replica of the code generated in the receiver. The time delay between the two signals provides a measurement of the distance to each satellite. The carrier phase positioning technique is an alternative to using the coded GPS data from the satellites. By directly observing the phase of the carrier wave on one or both frequencies, maximum accuracies are attainable. Furthermore, Leick (1990) reported that the carrier phase measurement is more accurate than the pseudo range measurement. In addition, different measurement methods such as Differential Global Positioning System (DGPS) and RTK should be used to achieve maximum accuracy. For GPS receivers, the information of the measurement methods, accuracy and price is given in Table 1.

Table 1. Measurement methods, accuracy and price for GPS receivers (Grisso et al. 2009).

Method	Accuracy (m)	Price ($)
GPS measurement	15	100 – 700
DGPS measurement	3 – 5	300 – 2000
DGPS measurement (WAAS, EGNOS vs.)	< 3	2000 – 6000
Real Time Kinematic	0,01 – 0,1	15000 – 60000

The requirement for GPS navigation accuracy is application dependent (Buick 2002). Some applications require high absolute accuracy, while others only need high relative accuracy (Han et al. 2004). For variable rate application and referencing of soil and yield data, an accuracy of one to several meters is generally sufficient. More accurate systems would be useful for vehicle guidance, to eliminate skips and overlaps with a chemical applicator, or for precision cultivation operations (Auernhammer and Muhr 1991; Han et al. 2004).

The Institute of Navigation (ION 1997) has developed test procedures to quantify the static navigation accuracy of GPS receivers. For simplicity, many GPS manufacturers report GPS accuracy using stationary test data. However, most agricultural applications, such as tillage, planting, spraying, and harvesting, in which the GPS receivers are used under dynamic conditions, are mobile operations (Han et al. 2004). Also, Han et al. (2004) reported that the GPS accuracy data provided by GPS manufacturers may not accurately characterize the actual performance of the receivers for many precision agriculture applications. In addition, Stombaugh et al. (2002) reported that the static performance of a GPS receiver is not necessarily the same as its dynamic performance.

Han et al. (2004) developed a method to evaluate the DGPS dynamic position accuracy under linear parallel-tracking applications. Eight commercially available DGPS receivers were used to collect navigation data and consequently to quantify the receivers' dynamic position accuracy under different dates, times of the day, and travel speeds. All eight DGPS test units were connected to the PC using RS-232 communications protocol. A program was developed to simultaneously record all the test data. Test platform was built and installed on top of a Patriot XL Sprayer (Figure 1). Five different differential correction signal sources were selected for the study (SF1, SF2, WAAS, OmniSTAR and Beacon). Each test consisted of six parallel passes, and each pass was approximately 305 m long (Figure 2). The test processes were conducted at North – South directions. The desired pass-to-pass spacing was 6.10 m. A total of 68 tests were conducted at different dates, different times of the day and at different vehicle speeds. Researchers found that the dynamic performance of a receiver was extremely variable from test to test and the pass-to-pass average error provided a good statistical measure of the GPS dynamic accuracy.

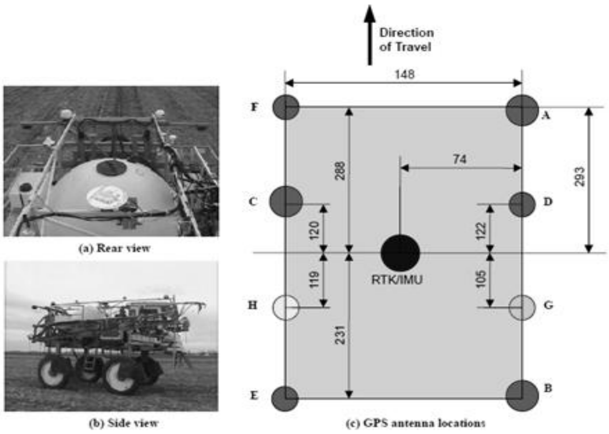

(a) Rear view
(b) Side view
(c) GPS antenna locations

Figure 1. Test vehicle, test platform, and GPS antenna locations (Han et al. 2004).

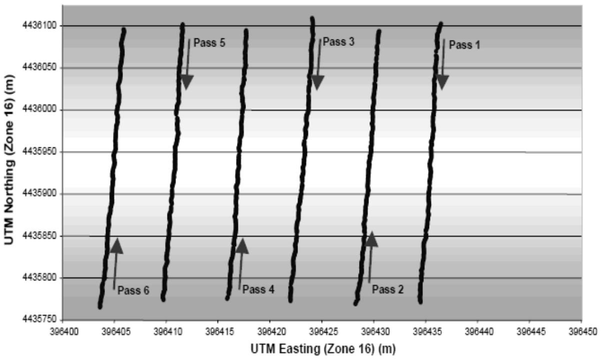


Figure 2. Vehicle passes from a typical test and six parallel passes in a single test (Han et al. 2004).

Taylor et al. (2004) developed test procedures for dynamically evaluating GPS receivers using a straight−line fixture. GPS receivers were dynamically tested on a 0.8 km length of railroad track using a small rail cart (Figure 3). The tests were conducted in both directions (east - west) and at two different speeds (8, 19 km h^{-1}). Cross−track and pass−to−pass errors were determined for a John Deere StarFire receiver with dual−frequency correction and a Trimble AgGPS 132 in autonomous mode. The GPS receivers were evaluated over a 24 h period. Researchers reported that pass−to−pass errors were more random than cross−track errors, with no clear concentrations of frequency content, implying that pass−to−pass accuracy tests can yield meaningful results in less time than required for cross−track accuracy testing.

Figure 3. GPS receivers mounted on the rail car for testing (Taylor et al. 2004).

Keskin and Say (2006) investigated the availability of low cost GPS receivers for measuring ground speed. In the study, two different low cost GPS receivers were placed about 0.3 m apart from each other on top of an agricultural tractor (Figure 4). Both receivers were interfaced to the laptop through the serial communication (COM) port. Statistical analysis was carried out to study the significance of the differences in the GPS speed data for the three different dates and repetitions. As a result, researchers reported that the low-cost GPS receivers can be confidently used to measure the ground speed in agricultural machinery operations (R^2>0.99).

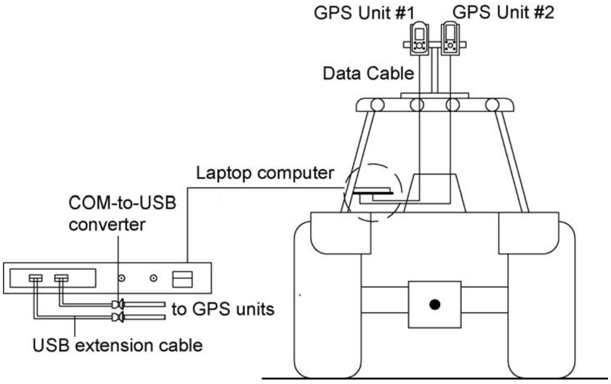


Figure 4. GPS speed measurement system (Keskin and Say 2006).

The main objective of this research was to develop a method to compare and evaluate the dynamic position accuracy of GPS receivers under dynamic linear conditions. Two commercially available GPS receivers were used to collect navigation data and consequently to quantify the receivers' dynamic position accuracy. The DRMS (Distance Root Mean Squared) method was used to calculate accuracy values of each receiver. So, navigation data of each GPS receiver was mapped. In addition, according to each GPS receiver data, cross track errors and travel speed data were statistically analyzed.

2. Materials and Method

2.1 Materials

In this study, two commercially available GPS receivers were used to accuracy test process. Technical information of the test receivers are given in Table 2. The Promark 500 receiver has dual-frequency (L1, L2) architecture, whereas the other receiver is single – frequency (L1) systems. It can be connected to Corse-TR (Continuously Operating Reference Stations-Turkey) via a phone data card to receive correction signals. For Garmin Etrex Legand receiver, correction signals were not used.

The GPS receivers were straightly placed about 0.2 m apart from each other on top of an agricultural tractor (Figure 5). According to the catalog data, Promark 500 receiver was selected as a reference receiver.

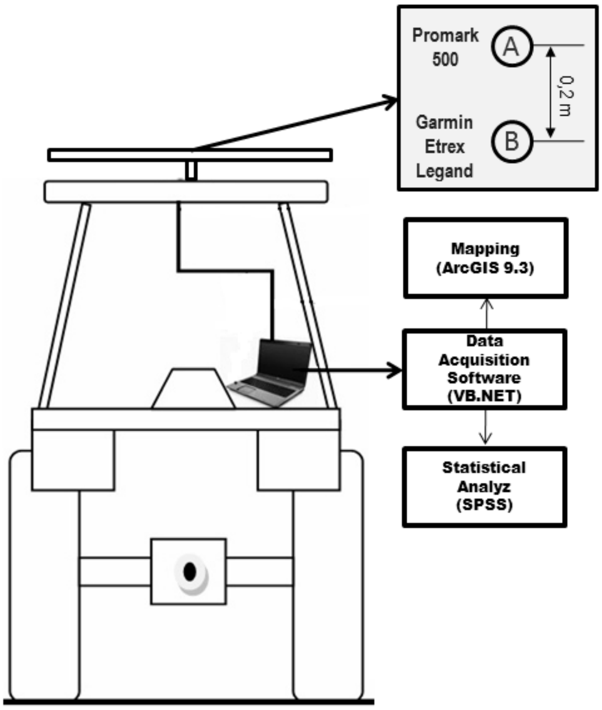


Figure 5. The arrangement of the GPS receivers, test vehicle and the test system.

A laptop computer was used to collect GPS data. The RS-232 serial communication protocol was used between the GPS receivers and the laptop. Serial communication speed of the GPS receivers was set 4800 baud to ensure synchronization. GPS data was saved to the database every 1 second. The data acquisition software was developed in Microsoft Visual Basic.NET programming language. All GPS data was stored to the Microsoft SQL Server 2005 database. ArcGIS 9.3 mapping software was used to mapping GPS position data. Microsoft Excel 2010 was used to analyze the GPS data.

Table 2. Technical information for the test receivers.

Code	GPS Receiver	Measurement Method	GPS Accuracy	DGPS Accuracy	RTK Accuracy	Update Rate	Price
A	Magellan Promark 500	RTK – CORS	-	< 1 m	< 50 mm	20 Hz	15000 $
B	Garmin Etrex Legend	GPS	< 15 m	3 – 5 m	-	1 Hz	200 $

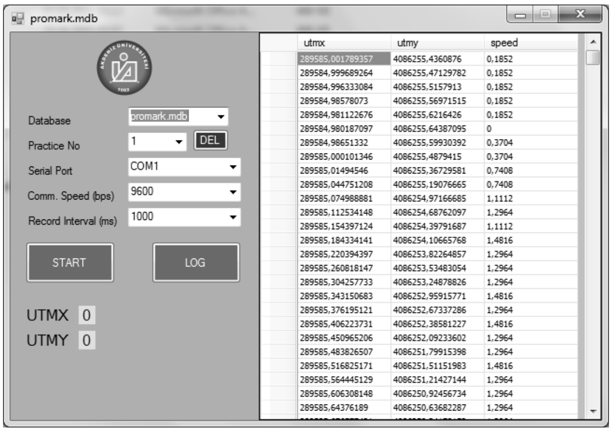
2.2 Method

Field tests were conducted in April 2011 at the Research and Application Land, Faculty of Agriculture, University of Akdeniz, Antalya, Turkey. The research area is located approximately 20 km from Antalya between the coordinates of 30.84 E and 36.94 N. The designed system was connected to a Massey Ferguson 3095D four-wheeled tractor. The test vehicle was manually driven along the north – south direction as straight line as possible. The test vehicle was driven six times at six different speeds (2, 4, 6, 8, 10 and 12 km/h). Each straight line was approximately 100 m long.

GPS receivers send data such as latitude, longitude, speed, time, etc. with cable to other electronic devices via RS-232 serial port in NMEA (National Marine Electronic Association) 0183 format. NMEA 0183 is a standard protocol, use by GPS receivers to transmit data. All NMEA data is emitted as ASCII data. Latitude and longitude data received from a GPS receiver in the NMEA-0183 format is in unit's ddmm.mmmm, where dd equals degrees, *mm* equals minutes, and *.mmmm* is decimal minutes. For many purposes, position information in this format is more than adequate. However, when plotting position information on maps or carrying out supplemental calculations using the position coordinates, it can be advantageous to work instead with the corresponding grid coordinates on a particular map projection. One of the most widely used map projection and grid system is the Universal Transverse Mercator (UTM) system. UTM grid coordinates are related to geodetic coordinates, and indicates the corrections to be applied to grid distance and bearings to get the actual true quantities on the earth' s surface (Topakci et al. 2010). For this reason, data that received from GPS receivers was converted to UTM format, and stored to the database by the software. The interface of the developed software is shown in Figure 6.

The GPS measurement error can be divided into two components: a cross-track error (XTE) perpendicular to the direction of the travel, and a track error (TE) parallel to the direction of travel (Figure 7). The ideal vehicle trajectories for most agricultural applications, such as tillage, planting, spraying, and harvesting, should be made of parallel passes separated by a uniform distance *W*. If the actual distance is greater than *W*, there is a skip, and if the actual distance is less than *W*, there is an overlap. Obviously, the XTE is the most important variable that affects the skip or overlap (Han et al. 2004).

Given that one of the main uses of GPS in agriculture is guidance, and XTE is the most important measure of performance. Our test track was oriented south-north, the XTE and the easting error were practically synonymous. We refer to easting error as XTE. XTE is the distance between your current position and the planned route. The regression line of the GPS data was used as a reference line. The reference lines were calculated individually for each plot within each test. XTE was expressed as the distance (northing or easting) between GPS data and the reference line.



Database: promark.mdb
Practice No: 1
Serial Port: COM1
Comm. Speed (bps): 9600
Record Interval (ms): 1000
UTMX 0
UTMY 0

utmx	utmy	speed
289585,001789357	4086255,4360876	0,1852
289584,999689264	4086255,47129782	0,1852
289584,996333084	4086255,5157913	0,1852
289584,98578073	4086255,56971515	0,1852
289584,981122676	4086255,6216426	0,1852
289584,980187097	4086255,64387095	0
289584,98651332	4086255,59930392	0,3704
289585,000101346	4086255,4879415	0,3704
289585,01494546	4086255,36729581	0,7408
289585,044751208	4086255,19076665	0,7408
289585,074988881	4086254,97166685	1,1112
289585,112534148	4086254,68762097	1,2964
289585,154397124	4086254,39791687	1,1112
289585,184334141	4086254,10665768	1,4816
289585,220394397	4086253,82264857	1,2964
289585,260818147	4086253,53483054	1,2964
289585,304257733	4086253,24878826	1,2964
289585,343150683	4086252,95915771	1,4816
289585,376195121	4086252,67337286	1,2964
289585,406223731	4086252,38581227	1,4816
289585,450965206	4086252,09233602	1,2964
289585,483826507	4086251,79915398	1,2964
289585,516825171	4086251,51151983	1,4816
289585,564445129	4086251,21427144	1,2964
289585,606308148	4086250,92456734	1,2964
289585,64376189	4086250,63682287	1,2964

Figure 6. Developed software for collection GPS data.

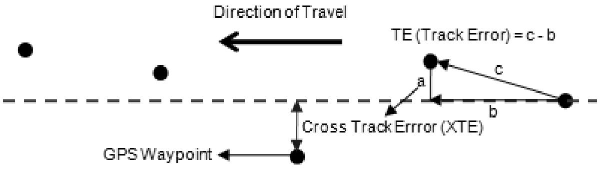


Figure 7. Definitions of GPS measurement errors

In this study, we collected latitude and longitude coordinate values for each GPS receiver. And so, GPS coordinate values were converted to UTM coordinates by the developed software. Also, DRMS was calculated to estimate GPS positional error in terms of accuracy for each receiver. For DRMS calculations, horizontal accuracy was calculated by the Equation 1 (Perez at al. 2006).

$$\sigma_{H\_acc} = \sqrt{\sigma_N^2 - \sigma_E^2} \tag{1}$$

where; σ_{H_acc} is DRMS; σ_N and σ_E are the standard deviation of the positional error along Northing and Easting directions respectively that are calculated by Equations 2 and 3 (Perez at al. 2006):

$$\sigma_N^2 = \frac{\sum_{i=1}^{n}(N_i - \overline{N})}{n-1} \tag{2}$$

$$\sigma_E^2 = \frac{\sum_{i=1}^{n}(E_i - \overline{E})}{n-1} \tag{3}$$

where; n is the total number of points; E_i and N_i indicate the location of i_{th} point along Northing and Easting directions, respectively; *E* and *N* are the sample mean of the measurements along Northing and Easting directions, respectively.

In this study, standard deviations and standard errors of the XTE values and DRMS values of straight lines for each receiver were calculated and analyzed. Travel speed effects on the DRMS were analyzed by using the analysis of variance (ANOVA) on the SPSS statistics software. Also, positioning data which was collected from each receiver was mapped by using ArcGIS 9.3 mapping software.

3. Results and Discussion

During the experiment, collected GPS coordinate values for each receiver were mapped by the ARCGIS 9.3 mapping software. The UTM coordinate map for all values is presented in Figure 8. It is seen from Figure 8 that coordinates values of the Promark 500 receiver are visually more linear than the Garmin Etrex Legand.

For horizontal accuracy calculation, linear regression analyses were performed by the Excel 2007. Linear regression analysis was used to find the straight line that best fits the data. With linear regression analyze, the XTE values were calculated. Depending on the XTE values, horizontal accuracy calculation was performed. The relationship between the UTM coordinates (x, y) and regression lines are shown in Figure 9. The results of the regression analyze show that the Promark 500 receiver (R^2>0.99) under dynamic conditions is slightly more linear than Garmin Etrex Legand receiver (R^2>0.98).

Standard deviation, standard error of the XTE values and horizontal accuracy values (δ_{H_acc}) are shown in Table 3. The comparisons of the horizontal accuracy values show that the horizontal accuracy of the dual frequency (Promark 500) receiver is approximately two times more accurate than the single frequency (Garmin Etrex Legand) under dynamic conditions. Also, according to the statistical analysis (ANOVA), the effects of the travel speed on the horizontal accuracy were

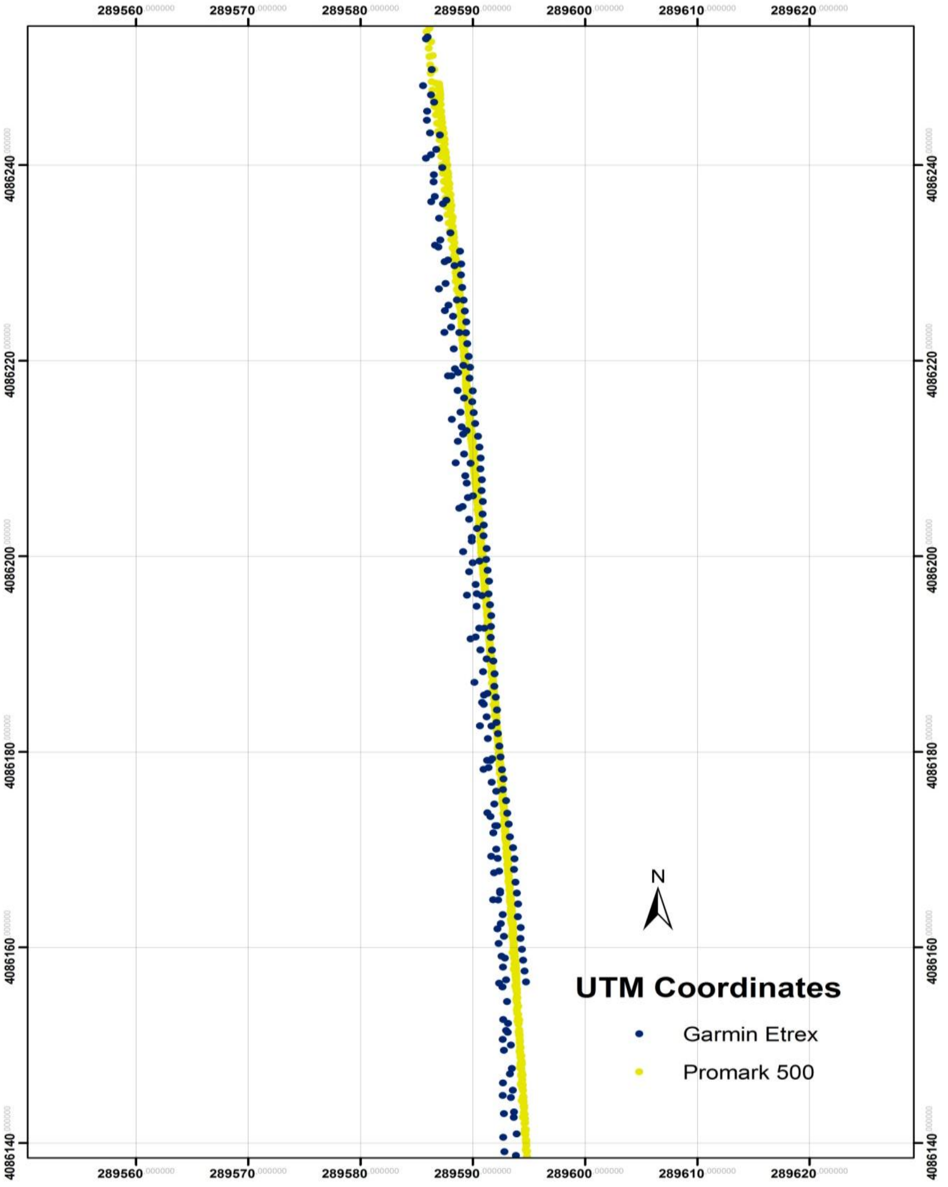


Figure 8. UTM Coordinate map for collected GPS data.

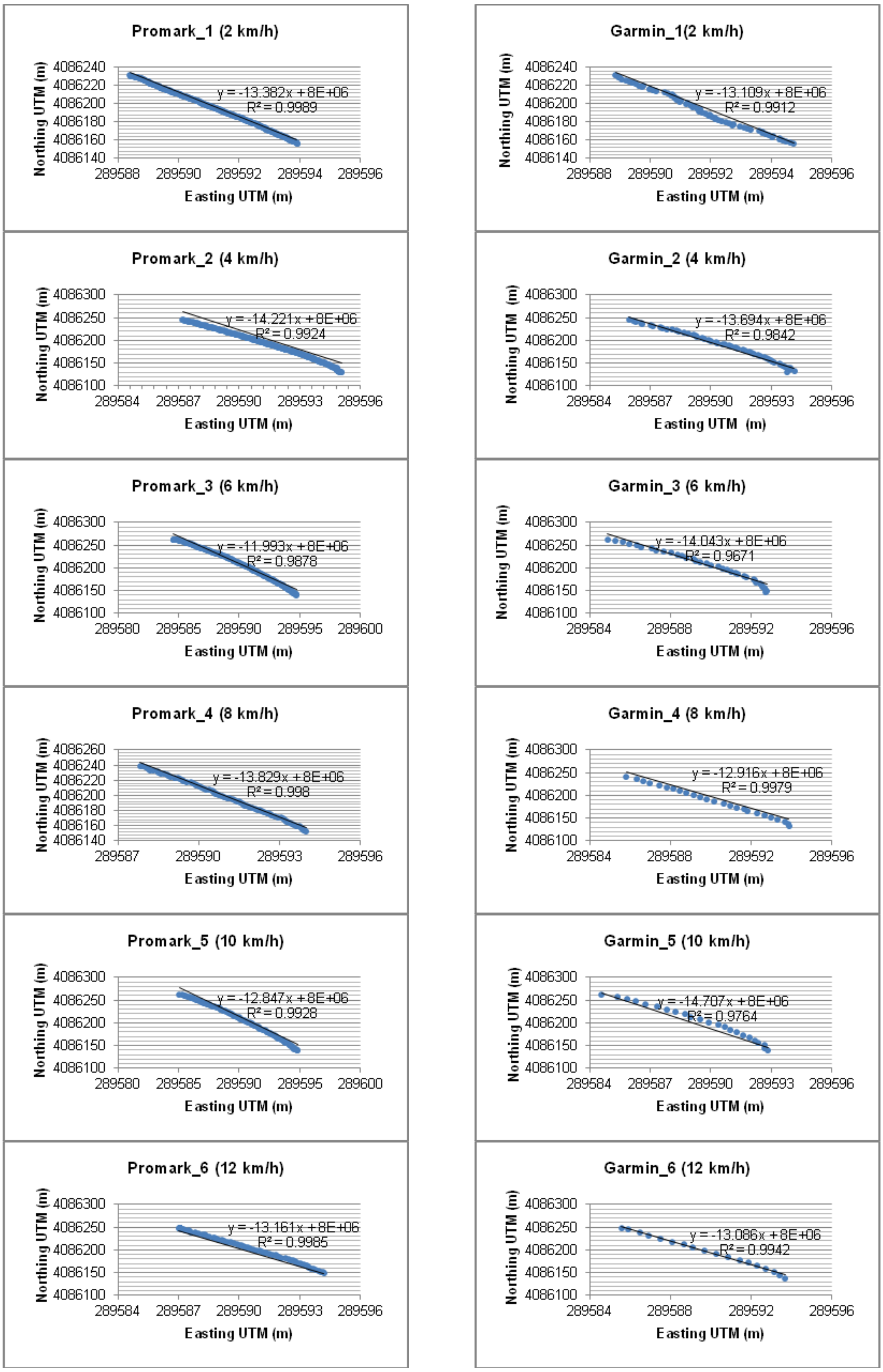


Figure 9. The relationship between the UTM coordinates (x, y) and regression lines.

Table 3. Test results.

Receivers	Test No	Speed (km/h)	Standard deviation of the easting XTE values (m)	Standard error of the easting XTE values (m)	Standard deviation of the northing XTE values (m)	Standard error of the northing XTE values (m)	Horizontal Accuracy (m)	R Square (R^2)
Garmin Etrex Legand	1	2	0.159	0.159	2.081	2.097	2.075	0.9912
	2	4	0.316	0.317	4.327	4.369	4.315	0.9842
	3	6	0.456	0.455	6.397	6.490	6.380	0.9672
	4	8	0.116	0.118	1.493	1.526	1.489	0.9979
	5	10	0.401	0.406	5.901	6.040	5.888	0.9764
	6	12	0.205	0.211	2.685	2.768	2.677	0.9942
Magellan Promark 500	1	2	0.055	0.055	0.730	0.732	0.728	0.9988
	2	4	0.206	0.206	2.933	2.940	2.926	0.9925
	3	6	0.344	0.343	4.128	4.141	4.113	0.9878
	4	8	0.084	0.085	1.165	1.173	1.162	0.998
	5	10	0.242	0.243	3.115	3.132	3.105	0.9928
	6	12	0.090	0.090	1.187	1.191	1.184	0.9985

not significant for both receivers. As a result; single frequency GPS receivers can be used safely in applications requiring linearity for different travel speeds.

4. Conclusions

The ideal vehicle trajectories for most agricultural applications, such as tillage, planting, spraying, and harvesting, should be made of linear and parallel. However, most agricultural applications, such as tillage, planting, spraying, and harvesting, in which GPS receivers are used under dynamic conditions, are mobile operations. It is proposed that the horizontal linear accuracy (DRMS) is the most important criterion in evaluating a receiver's dynamic performance for those applications.

In this study, two commercially available GPS receivers were used to collect navigation data and consequently to quantify the receivers' dynamic position accuracy. The DRMS method was used to calculate accuracy values of each receiver.

So, navigation data of each GPS receiver was mapped. In addition, according to each GPS receiver data, cross track errors and travel speed data were statistically analyzed.

The results of the regression analysis show that the Promark 500 receiver (R^2>0.99) under dynamic conditions is slightly more linear than Garmin Etrex Legand receiver (R^2>0.98). The results of the horizontal accuracy calculation show that the horizontal accuracy of dual frequency (Magellan Promark 500) receiver is approximately two times more accurate than the single frequency (Garmin Etrex Legand) under dynamic conditions. Also, according to the statistical analysis (ANOVA), the effects of the travel speed on the horizontal accuracy were not significant for each receiver.

In conclusion, Both Promark 500 and Garmin Etrex Legand receiver can be used to applications that require linearity in precision agriculture applications. But, the Promark 500 receiver must be used to applications that require higher accuracy.

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