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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Developing A Field Test Method for Automatic Steering Systems

Otomatik Dümenleme Sistemleri için Bir Arazi Testi Yöntemi Geliştirme

Maksut Barış EMİNOĞLU[1*], Uğur YEGÜL[2], Ufuk TÜRKER[3]

Abstract

Precision agriculture (PA) refers to planning and managing the processes from tillage to harvest using modern technology and techniques in order to increase the productivity of the cultivated crops. One of the most important components of PA equipment is the location determination and verification unit. Automatic steering systems, which have started to be included in developing agricultural machines, enable reaching the targeted locations with the least deviation from the determined route. These systems are provided accurately to navigate the fields, ensuring that crops are planted, fertilized, sprayed and harvested with precision. By reducing overlaps and skips in planting and other tasks, farmers can optimize their resources and maximize yields. The use of automatic steering systems in precision agriculture not only increases efficiency but also helps to minimize environmental impact by reducing the use of inputs such as fertilizer and pesticides. In this study, simple equipment that can be connected to the tractor's three-point linkage system was developed for pass-to-pass verification tests of the automatic steering systems in the field. For the field test, the narrowest and widest inter-row spacing that the automatic steering system was adjusted to have been taken into consideration. For the narrowest inter-row spacing, it was set to 3m; for the widest inter-row spacing, it was set to 18m. The automatic steering system was tested three times for each of the two different inter-row spacings. At the same time, the position information during the trial hours was compared with the records in the log files in the software part of the automatic steering system. Pass-to-pass tests were conducted based on ISO 12188-2:2012(EN) Tractors and Machinery for Agriculture and Forestry (Part 2). As a result of the evaluations, statistically significant difference wasn't found between the values obtained from the field trials with developed equipment and the results obtained from the log files of the automatic steering system. The results show that this developed equipment can be used practically in pass-to-pass tests in the field.

Keywords: Automatic steering system, Pass to pass test, Accuracy

[1]***Sorumlu Yazar/Corresponding Author:** Maksut Barış Eminoğlu, Ankara University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, Ankara, Türkiye. E-mail: eminoglu@agri.ankara.edu.tr OrcID: 0000-0003-3264-3636
[2]Uğur Yegül, Ankara University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, Ankara, Türkiye. E-mail: yegul@ankara.edu.tr OrcID: 0000-0003-2139-4080
[3]Ufuk Türker, Ankara University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering, Ankara, Türkiye. E-mail: uturker@agri.ankara.edu.tr OrcID: 0000-0002-7527-7376
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Öz

Hassas tarım (HT), yetiştirilen ürünün verimliliğini artırmak amacıyla modern teknoloji ve teknikler kullanarak ekimden hasada kadar olan gerçekleştirilen tarımsal işlemlerin planlanması ve yönetilmesi anlamına gelir. HT ekipmanlarının en önemli bileşenlerinden biri konum belirleme ve doğrulama birimidir. Gelişen tarım makinelerine dahil edilmeye başlanan otomatik dümenleme sistemleri, belirlenen rotadan en az sapma ile hedeflenen konumlara ulaşmayı sağlamaktadır. Bu sistemler, arazide doğru bir şekilde yönlendirme sağlamak için tasarlanmıştır ve yetiştirilecek ürünlerin hassas bir şekilde ekilmesini, gübrelenmesini, ilaçlanmasını ve hasat edilmesini amaçlamaktadır. Tarımsal faaliyetler sırasında aynı alanın tekrar işlenmesini veya işlenmeyen alanları azaltarak, çiftçilerin kaynaklarını optimize edebilir ve verimlerini artırabilirler. Otomatik dümenleme sistemlerinin hassas tarımda kullanımı sadece verimliliği artırmakla kalmaz, aynı zamanda gübre ve pestisit gibi girdilerin kullanımını azaltarak çevresel etkiyi de en aza indirir. Bu çalışmada, otomatik dümenleme sistemlerinin üst üste geçiş doğrulama testlerinin arazide yapılabilmesi için traktörün üç nokta askı düzenine bağlanabilen basit bir ekipman geliştirilmiştir. Arazide gerçekleştirilen test için otomatik dümenleme sisteminin ayarlanabildiği en dar ve en geniş sıra arası mesafeler göz önüne alınmıştır. En dar sıra arası mesafe için 3m; en geniş sıra arası mesafe için 18 m olarak otomatik dümenleme sistemi ayarlanmış; iki farklı sıra arası mesafe için üçer tekrarlı denemeler gerçekleştirilmiştir. Aynı zamanda, deneme saatleri boyunca konum bilgileri, otomatik yönlendirme sisteminin yazılım kısmındaki günlük dosyalarındaki kayıtlarla karşılaştırılmıştır. Üst üste geçiş testleri, ISO 12188-2:2012(EN) Tarım ve Orman için Traktörler ve Makineler (Bölüm 2) esas alınarak gerçekleştirilmiştir. Değerlendirmeler sonucunda, geliştirilen ekipmanla yapılan saha denemelerinden elde edilen değerler ile otomatik dümenleme sisteminin günlük kayıt dosyalarından elde edilen sonuçlar arasında istatistiksel olarak anlamlı bir fark bulunmamıştır. Sonuçlar, geliştirilen bu ekipmanın sahada üst üste geçiş testlerinde pratik olarak kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Otomatik dümenleme sistemi, Üst üste geçiş testi, Doğruluk

1. Introduction

Precision Agriculture (PA) refers to planning and managing the processes from tillage to harvest using modern technology and techniques in order to increase the productivity of the grown product. PA technologies integrate control, electronics, computers, databases, and computational expertise to offer a sophisticated systems approach. Through the use of remote sensing technologies, geographic information systems, global positioning systems, and variable rate applications, PA technologies replace the traditional fixed-level application methods used across the field with a system that focuses on variable rate applications. This is accomplished by assessing soil and plant properties for much smaller portions of the field, such as soil moisture, plant nutrient levels, soil texture, crop conditions, yield, etc. The soil is tilled to varying depths, planting is done at varying norms, irrigation and drainage are applied at varying levels, and each portion receives the quantity of fertilizer or pesticide it requires. This approach, therefore, strives for more cost-effective and ecologically sustainable production (Özgüven and Türker, 2009).

One of the most important components of precision agriculture equipment is the location determination and verification unit. Automatic steering systems, which have started to be included in developing agricultural machines, enable reaching the targeted locations with the least deviation from the determined route. Effective using of agricultural inputs is possible with automated agricultural mechanization. With auto-steering tractors, rows can be tilled in parallel, and agricultural operations such as planting, fertilizing, and spraying can be performed more efficiently. These systems have been developing since the 1960s and it continues to evolve (Ming et. al., 2009). Li et al. (2019) introduced a cutting-edge navigation system designed for autonomous tracking of a guided vehicle, showcasing significant advancements in precision agriculture technology. The system comprises a master vehicle and a slave machine, working in tandem to execute autonomous navigation tasks effectively. The master vehicle can use an autopilot or be driven manually, while the slave vehicle adapts to its shape to carry out the navigational tasks automatically. A location unit, a steering controller, a wireless communication unit, and a vehicle terminal device make up the automatic navigation system, which uses a steering control method. The master-slave navigation system's vehicle terminal software is built to incorporate modules for controlling tracking, data connection, navigation, and positioning of agricultural machines. Experimental findings demonstrate reliable system performance and the ability of the slave to follow the master vehicle autonomously at a speed of 0.8 m s^{-1}.

Recent studies on automatic steering systems have noted improvements in response stability during critical time delays, increased time efficiency in headland turns, and reductions in lateral position deviations (Limpinski et al., 2016; Ye et al., 2020; Yang et al., 2022; Jing et al., 2023).

Automatic steering systems offer a multitude of benefits including reduced seed, fertilizer, and pesticide inputs, minimized machinery use, decreased operator stress, while enhancing work efficiency, fuel efficiency, and time management. Automatic guidance systems minimize stress and fatigue through permitting operators to focus on tasks outside steering (Burgers and Vanderwerff, 2022). Also, that is confirmed automatic steering systems provide many benefits and support the larger goal of agricultural production sustainability (D'Antonio et al., 2023). Topcueri et al., (2024) stated that automatic steering technology provides advantages in reducing differences in inter-row spacing between successive plants. Therefore, the automatic steering systems should be applied carefully with appropriate configurations to maximize advantages.

To provide these advantages, the system should have high operational accuracy in terms of overlapping or skipping. These values are supposed to be between 2-3 cm for automatic steering systems. Therefore, it is important to assess the system's performance, especially in field conditions together with tractor and equipment. Standard tests are available, especially for the global positioning systems (GPS), global navigation satellite system (GNSS), real-time kinematic (RTK), or real time extended (RTX) for positional accuracy at concrete or asphalt track level (ISO 12188-2:2012).

Point Test (Static test - Source of GNNS, GPS or RTK, RTX), Line Test and Pass to Pass Accuracy Test are carried out to assess the accuracy of automatic steering systems. The tests based on ISO 12188-2:2015 standard for testing the accuracy of automatic steering systems and deviation amounts claimed by the company are carried out on hard ground (asphalt, road, etc) and when any equipment is attached to the tractor. In addition to other tests in the standards, the tractor is tested according to the Reference Point (RVP) along the direction (XTE test) (during these tests no forces appear). However, when determining these deviations, the compatibility of the tractor equipment combination in the field cannot be taken into account, especially during these tests and operations, lateral forces caused by the equipment behind, especially soil machines, can cause deviations in the tractor route, especially in the XTE line. This situation can reveal situations that the farmer can only realize after the operations and negatively affect his operations. If the first XTE line is not created properly, deviations that cause this skip or overlapping can occur in the next turn. In order to avoid these situations, especially to make quick adjustments in the field, to correct negative situations, this apparatus will allow the farmer to quickly see the deviation of the tractor equipment combination from the XTE line (in the first line) and it will be possible to correct this situation and adjust the settings at the beginning of the job. Therefore, this system is not an alternative to the tests of steering systems, but it has been developed only to provide additional support for the detection of deviations from the first straight line created in the field operation, which will also ensure the control of tractor and equipment compatibility.

Based on this idea, an apparatus unit has been developed in this study that contributes to the testing method of an automatic steering system that can be used in field trials. This apparatus was developed to practically determine the relative cross-track error (XTE) value in the field. An application of a method for determining the XTE value has been carried out.

2. Materials and Methods

2.1. Automatic steering system

The automatic steering system consists of a display screen, a receiving antenna that receives signals from the RTK-based CORS TUSAGA active system, a motorized steering wheel, and an angle sensor (*Figure 1*). The manufacturer states that the system's accuracy is ± 2 cm. The basic technical specifications of the system are provided in *Table 1*.

Table 1. Technical specifications of the tested automatic steering system

Constellations	GPS, GLONASS, Galileo, Beidou and QZSS
Ingress Protection	IP 67
Communication	Bluetooth, Wi-fi
Receiver	GNSS
Accuracy	± 2 cm
Screen width	25.6 cm
Steering	Electrical
Other features	Support for external camera Land registration Transaction path recording Ability to work with a SIM card Connection with RTK stations Possibility of remote control

2.2. Specification of test conditions

The automatic steering system was mounted on a 4WD agricultural tractor equipped with a 93 kW diesel engine. During the field trials, the tractor’s forward speed was adjusted and maintained at a constant 2 m s^{-1}. The trial field was located Ankara, Kahramankazan province (40°04'23.3"N, 32°37'46.0"E) with a total area of 2 ha. The field surface was covered with stubble, and the slope ranged between 3–5%. The automatic steering system was tested on two selected working widths; 3 m referencing a tillage machine and 18 m referencing a sprayer.

2.3. Test procedure of automatic steering system

The field pass-to-pass tests were conducted in accordance with ISO 12188-2:2012(EN) Tractors and Machinery for Agriculture and Forestry (Part 2). Before the test, all elements of the automatic guidance system were properly installed. All settings were reset to factory defaults. The tests were carried out using correction signals provided by RTK TUSAGA. The reference line was established one hour before the first test. For a given rate of advance, each test was performed three times for two consecutive days with different arrays of GNSS satellites. The start time of each test sequence was randomly assigned. The automated guided vehicle system was allowed at least 10 seconds in equilibrium operation before entering each designated test area. To ensure variability in GNSS positioning quality, consecutive test runs were spaced more than one hour apart. More than a 24-hour time period was allowed between the first and last test.

Figure 1. Automatic steering system used for trial (a: antenna, b: motorized steering wheel, c: display screen, d: angle sensor)

2.4. Designed apparatus for testing automatic steering systems

An apparatus was designed within the frame to determine the lines that are referencing the tractor's middle axis when the automatic steering system is working. The frame is manufactured according to the dimensions of the three-point linkage system (TS ISO 730, 2021) and then connected to the three-point linkage system. At the bottom of the frame, a plate was welded to the frame as its hole axis coincided with the center axis of the tractor. After the designed apparatus was connected to the tractor's three-point linkage, the arms that adjust the looseness of the lower links were tightened to minimize the sway of the tractor's three-point linkage lower links. Representative vehicle point (RVP) was created by aligning the centers of the holes that tractor drawbar and the plate included in the designed apparatus. *Figure 2* and *3* contain images from preliminary tests explaining the attachment of the designed apparatus to the tractor and the measurement method.

In the center of this frame, there was also a shaft with a roller on it. The first point was to assess the projection of the hole on the tractor drawbar line on the ground. When the tractor moves during the tests the pulley rotates and the rope on it determines the line followed by the tractor center axis. The second line was created by assigning the agricultural equipment width from the menu of the automatic steering system. Using tape measures, the distance intervals to be measured on the line were determined with the line starting points as reference. Subsequently, the distance of the two lines from each other was measured at the determined intervals (*Figure 3*).

Figure 2. Developed apparatus for automatic steering system testing

Figure 3. Measuring the width of lines for XTE test

The visuals related to the measurements of the designed apparatus and measurement method conducted in the field trials are provided in *Figure 4*.

Figure 4. Field experiments of designed apparatus

2.5. Determining lines from automatic steering system log files

In this method, the location data in the automatic steering system's log file was processed on the Google Earth program. The horizontal distance between the two lines was measured at intervals determined according to the reference point (*Figure 5*). Measurement values that are more than the set equipment width are called skip; values that are narrower than the set equipment width is called overlap. Overlap or skip conditions were determined according to the distance value between the lines determined in the automatic steering interface.

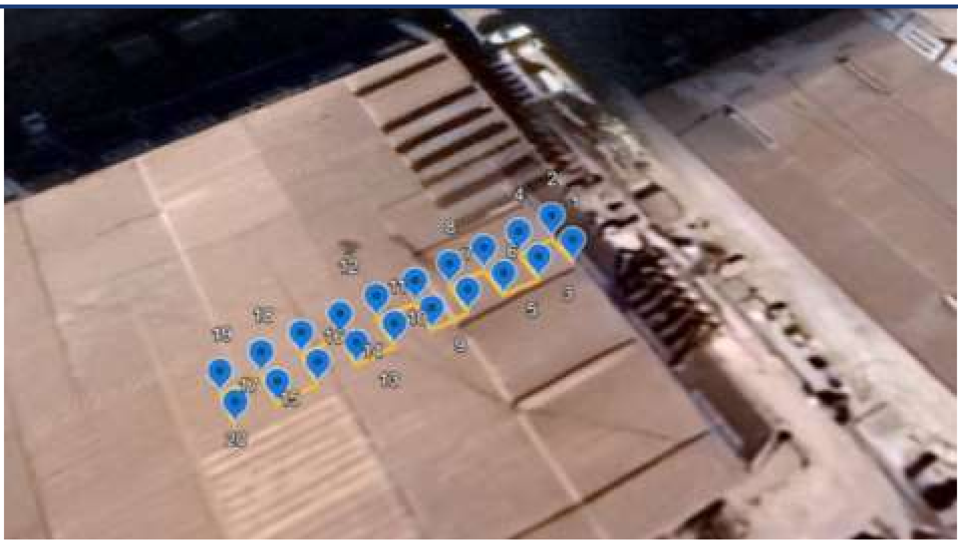

Figure 5. Determining line widths from log file

Measurements were taken every five meters to determine the relative cross-track error (XTE) values of parallel lines to compare both methods in this regard. Thus, deviations (overlap, skip) that could occur along the direction of movement were identified. The values obtained from the two different methods were compared with the results recorded in log files and field measurements.

2.6. Statistical analysis method of values

In terms of interval distance measurements taken every 5 m, whether there is a statistically significant difference between the values obtained from the memory of the automatic steering system and the developed method was determined using an independent samples t-test. Statistical analyses were performed using the MINITAB 16 software package.

3. Results

The work width of three meters in the table represents the working condition with a tillage implement and the work width of eighteen meters represents the working condition with a sprayer. The overlap or skip conditions can impact the efficiency and effectiveness of the equipment, as well as the overall quality of the work being done. It is important to monitor and adjust these settings to ensure optimal performance in the field. *Table 2* shows the measured distance of lines in the developed method column and calculated values from the automatic steering system log files column.

The values greater than 3000 and 18000 mm in the *Table 2* can be considered as overlap, while the values less than 3000 and 18000 mm can be considered as skip. This categorization helps define the dataset's values and understand the existing patterns. It can help in making preliminary assessments based on the values falling within these ranges. When the *Table 2* was examined, although one method was marked as overlap and the other as skip, it was observed that there were differences at the boundary of the ±20 mm error margin of the automatic steering system. Descriptive statistics related to the methods are provided in *Table 3*.

The differences between the values obtained from the memory unit of the automatic steering system and the measurements made using the developed method, both for the 3 m and 18 m row spacing distances, were not found to be statistically significant ($p>0.05$). Therefore, it can be said that both measurement methods yield the same results. Graphs showing the confidence intervals for both methods at 3 m and 18 m working widths are provided in *Figure 6* and *7*.

These values are also the narrowest and widest inter-row distances defined in the interface of the automatic steering system used to test the developed method. Additionally, the statistical analysis of measurements confirmed that there was no significant difference between the methods tested for both working widths. This suggests that the developed method can be confidently applied in practical field settings.

Table 2. Measured working width values during field tests

Working width values					
3m			18m		
Distance from reference point (m)	Developed Method (mm)	Log Files (mm)	Distance from reference point (m)	Developed Method (mm)	Log Files (mm)
5	2995	3003	5	17994	18003
5	3005	2998	5	18005	17997
5	3001	3007	5	18001	18007
10	3007	3000	10	18007	18000
10	3000	3004	10	18000	18004
10	3003	2999	10	18004	17998
15	2994	3002	15	17994	18002
15	3002	2998	15	18002	17998
15	3003	3007	15	18003	18007
20	3006	3001	20	18006	18001
20	3000	3004	20	18000	18004
20	3002	2999	20	18004	17999
25	2996	3004	25	17996	18004
25	3004	2999	25	18004	17999
25	3002	3008	25	18002	18008
30	3008	3002	30	18010	18002
30	3001	3005	30	18001	18005
30	3005	2999	30	18005	17997

Table 3. Descriptive statistics of methods

Methods	Working width values					
	3 m			18 m		
	Mean±SEM[1]	Min	Max	Mean±SEM[1]	Min	Max
Developed Method	3001.9±0.921	2994	3008	18002±1.01	17994	18010
Log files	3002.2±0.768	2998	3008	18002±0.834	17997	18008

[1]SEM: Standard error of mean

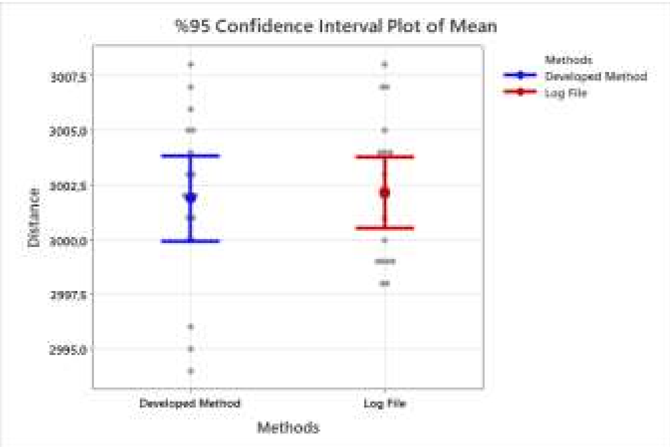

Figure 6. Confidence intervals for 3 m working width

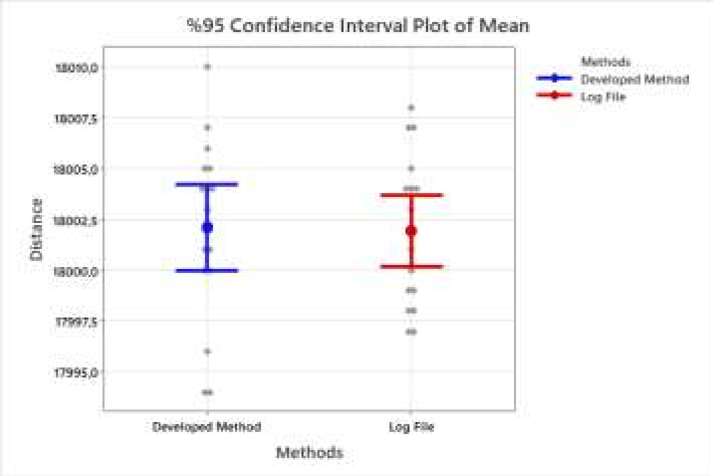

Figure 7. Confidence intervals for 18 m working width

4. Conclusions

This research introduced a novel method for assessing the accuracy and reliability of automatic steering systems in field trials. The method utilizes a specially designed apparatus.

When the values obtained during the field tests were compared, the difference between the methods was not found to be statistically significant. When looking at the study's results, the findings indicated that the equipment developed for testing automatic steering systems in the field gave results that were similar to the XTE tests done with the classical method for the smallest and largest row spacing distances of the automatic steering system that was used as the material. With this developed device, it is aimed to further develop the automatic steering system in the future in order to control the maintenance of the distance between the rows in the field after the normal standard tests. Especially tractors working with soil machines may cause the tractor to deviate from the working direction under the effect of lateral forces in the field. Since these deviations of the systems take a certain period of time, these deviations take effect and may cause the lines not to be formed properly in the next turn. In order to evaluate the reactions of a tractor equipped with an automatic steering system to the lateral forces it may encounter while working with soil machines, it is aimed to modify the designed device in the ongoing studies and use it together with soil tillage equipment.

With the designed apparatus and measurement method, it is aimed to practically perform the calibration and validation of the automatic steering system's XTE test under field conditions. Processing the position data obtained from the memory of automatic steering systems in a computer environment requires qualified operators and/or personnel. Therefore, this method has been developed to enable farmers and/or operators to perform practical control in the field. In the following studies, the apparatus developed will be suitable for working with tractors and equipment in the field. For future work, researchers aim to integrate to verify the reliability and sensitivity of the developed testing method using advanced technologies such as cameras and drones.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Eminoglu M.B., Türker., U.; Design: Türker, U., Eminoğlu, M.B.; Data Collection or Processing: Eminoglu M.B., Yegül, U., Türker., U.; Statistical Analyses: Eminoglu M.B.; Literature Search: Yegül, U., Eminoglu M.B.; Writing, Review and Editing: Eminoglu M.B., Yegül, U., Türker., U.

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