AUTOMATIC TRACTOR GUIDANCE SYSTEM BASED ON GLOBAL POSITIONING SYSTEM

by

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GRADUATE COLLEGE
UNIVERSITY OF NEBRASKA

AUTOMATIC TRACTOR GUIDANCE SYSTEM BASED ON GLOBAL POSITIONING SYSTEM

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An automatic tractor guidance system using the global positioning system (GPS) was developed to steer a tractor along a predetermined path. The guidance path was the Nebraska Tractor Test track. The length of a complete loop of the track is 586 m. The guidance path was defined by a series of 586 positions represented by easting and northing coordinates.

The GPS was operated using real time differential correction (DGPS). The DGPS provided positions (easting, northing) with circular error probable (CEP) of 5.5 m, and distance root mean square (DRMS) of 6.82 m. The maximum easting and northing errors were 12.7 m and 21.4 m, respectively. The DGPS positions of the moving tractor were not affected by the moving error. The average deviation of the DGPS positions of the moving tractor from the true locations was 6.2 m, and the standard deviation was 2.2 m.

Due to the fluctuation of the DGPS positions, a dead reckoning (DR) positioning method was coupled with the DGPS positioning to provide the guidance system with smoothed positions. A guidance control algorithm was developed to determine the proper steering angle to correct front wheel angle to follow the guidance path. The angular velocity

to steer front wheels varied with the amount of required steering and the time to reach the look-ahead position on the guidance path.

The automatic guidance system was evaluated through computer simulation and field test. Using a computer simulation, the system was evaluated at three travel speeds (1, 2, and 3 m/s). The simulated guidance paths were a step function and a sine wave function. The simulation test suggested that the average position error does not depend on travel speed at a probability of 0.05. In the field test, the automatic guidance system was tested at the low speed (1 m/s). The field test was to evaluate the system ability to complete one loop (586 m) of the Nebraska Tractor Test track which provided straight and turning patterns. The automatic guidance system controlled the tractor with a mean deviation of 18.65 cm from the guidance path, and a standard deviation of 2.3 m. Sixty eight percent of the actual position errors were less than the standard deviation for the DGPS positions of a moving tractor. The computed errors were compared with the measured errors of the guidance system. It was found that the computed errors by the program can be used to represent those errors measured with a measuring tape at a probability of 0.05.

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INTRODUCTION

For many years, researchers have been working on the development of automatic guidance systems for agricultural machines. Traditional agricultural guidance systems depend on mechanical methods that utilize features such as crop rows and furrows for guidance.

In typical agricultural field operations, the driver must devote considerable attention to the functions of the machine as it moves through the field. Attention to the guidance task is in direct competition with the need to monitor the operation of the farm equipment (Brandon, 1990). An automatic or assist guidance system appears to have potential to allow the driver to pay more attention to the implement function, less attention to guidance, and therefore reduce operator fatigue.

There are additional advantages that can be gained with the use of automated tractor steering control. Application equipment is usually very wide and is difficult to guide in the field without skips or overlaps of the passes. Over application can occur because of the overlap of the passes during an application. Elimination of the overlap areas by the use of a guidance system which follows a well defined path in the field would minimize environmental damage and increase profits. An automatic guidance system would also enable operators to perform night spraying and take advantage of light wind and low temperature conditions during the night.

Controlled traffic would also benefit from an automatic tractor guidance system. Controlled traffic is a crop production system in which rootbeds and roadbeds are distinctly

and permanently separated. This system establishes traffic lanes that are not tilled and are used for wheel paths year after year. The lanes become compacted, improving tractive efficiency and flotation, while the untrafficked crop zone, if initially well prepared, tends to stay that way without annual deep tillage (Taylor, 1982). Because the field equipment operates on the same traffic lanes, a guidance control system would be appropriate. A guidance control system can control the agricultural vehicles accurately to maintain the traffic zone and reduce soil compaction in the crop zone, thereby increasing yields.

Rapid advances in micro-electronic technologies provided the opportunity for their application to controls in agricultural systems (Stone, 1991). Tools are available that can assist in establishing a map or guidance path in the field. These tools are based on triangulation methods, laser (Shmulevich et al., 1987; Gordon and Holmes, 1988), radar (Smith and Schafer, 1981), and the global positioning system (Larsen et al., 1988; Ambuel et al., 1991; Petersen, 1991; Bashford et al., 1994). The global positioning system (GPS) has become the most widely used method to determine the location of agricultural machines while working in the field. It is based on the use of information transmitted by a constellation of satellites orbiting the earth.

The GPS is a new technology developed and operated by the United States Department of Defense to support military navigation. It can be used for navigation on land, sea, and in air. The GPS system gained rapid popularity during Desert Storm. It is now used for both military and civilian purposes. The satellites transmit at two frequencies, L_1 = 1575.42 MHZ and L_2 = 1227.6 MHZ, modulated with two types of codes, Course/Acquisition code (C/A-code) and the Precision code (P-code). The Standard

Positioning Service (SPS) which is based on the C/A-code is available to civilian users. Military users have access to the Precise Positioning Service (PPS) which is provided by the P-code.

There are many civilian uses of the GPS. It is used in boating to find boat location and navigate on the sea. In the field of land vehicle tracking and intelligent vehicle/highway systems, GPS technology assists in the management of public fleets for transportation, public safety, and emergency. In agriculture, the GPS system is becoming a useful tool to indicate the machine's position in the field.

OBJECTIVES

The objective of this study was to develop an automatic tractor guidance system based on the global positioning system (GPS). The guidance system needs to be portable and easily attached to any tractor. The specific objectives were to:

1. evaluate the position accuracy of the global positioning system equipment used in this research effort,
2. develop an automatic guidance system for tractors based on the global positioning system, and
3. evaluate the performance of the automatic guidance system.

LITERATURE REVIEW

Automatic Tractor Guidance System

Automatic guidance of agricultural vehicles has been a topic of major interest addressed during recent years (Félez et. al., 1989). An automatic guidance system has potential to allow the driver to devote more attention to the implement function and reduce operator fatigue.

A tractor guided by an operator is a closed-loop system in which the closure is effected by the operator. The steering mechanism, which governs the direction of the front wheels, is analogous to the forward loop of a conventional control loop. The operator corresponds to the feedback loop and the error detector. Unconsciously, he performs three distinct but simultaneous tasks. First, he determines the actual location of the tractor. Second, he compares this position with the desired position of the tractor. Third, he takes corrective action whenever the desired and actual position of the tractor differ. When compared to a conventional control system, the operator performs the tasks normally assigned to the sensor, error detector, controller and actuator (Grovum and Zoerb, 1970).

A path for the tractor to follow must first be defined for an automatic guidance control system. The path could be sensed by physical contact or non-contact positioning methods such as the use of lasers, ultrasonics, computer vision system or navigational systems.

Richey (1959) developed an "Automatic Pilot" for farm tractors. The guidance system depended on mechanical sensing to detect the location of a plant row relative to the tractor by feelers straddling the crop row. The feelers were mounted on a longitudinal pivot above the row and displaced far enough to activate micro-switches that controlled relays carrying

current to an electric motor. The motor turned the steering wheel when a guidance error was detected by the feelers. The system could control the tractor to follow the row within a band of approximately 10.2 cm (4 inches) at speeds up to 9.6 km/h (6 mph). However, the system required that corn plants must be at least 25 cm (10 inches) high with stalks at least pencil thick near the ground in order for the system to perform the guidance properly.

Grovum and Zoerb (1970) designed a marker-follower guidance system. A furrow was recognized by two sensor wheels positioned to roll on both sides of a furrow. When one of the sensor wheels rolled down into the furrow, an error signal was sent to the computer which controlled the rotation of a motor coupled to the steering wheel of the tractor. The operator steered on the headlands and when instability occurred while following the marker. Field tests of the system showed that the guidance system was very stable and displayed good following characteristics at a low speed of 2.4 km/h (1.5 mph). Also, optimum system performance was attained at a speed of 6.8 km/h (4.2 mph) with the sensor wheels mounted in line with the tractor front wheels.

Kirk et al. (1976) developed a furrow-following guidance system for tillage and seeding operations. The guidance sensor was mounted on a supporting arm extending in front of the tractor in line with the rolling direction of the right front tractor wheel. The supporting arm rotates in a horizontal plane. The guidance sensor consisted of a feeler attached to a potentiometer that generated an error signal when the forward end of the supporting arm was not in line with the rolling direction of the front wheel. The error signal controlled the rotation of a steering motor. The guidance system was tested in a rectangular field. The first pass was made around the outside of the field manually. With each pass of the tractor around

the field, a guidance furrow was made for the next pass. The guidance system performance was not affected by lumps or irregularities in the guidance furrow. The maximum following error was 5.1 cm (2 inches) at a speed of 7.2 km/h (4.5 mph).

McMahon et al. (1983) designed a steering control system using ultrasonic transducers as noncontact sensors to guide an over-the-row apple harvester. The sonar sensing system was positioned ahead of the front wheels of the harvester. The harvester's wheels were turned to an angle proportional to the harvester's lateral position error from a tree trunk. The performance of the steering control system was determined by examining the alignment of the harvester as it moved over the row. The test results showed that for the straight and curved rows, the steering control system was effective at keeping each tree stand within the harvester's allowable zone. The maximum deviation of the front and rear points on the harvester from the row centerline of straight rows was 5 cm. The maximum deviation for the curved rows was 8.7 cm at the front and 3.2 cm at the rear of the harvester.

Buried cable techniques have been used for tractor guidance to determine the proper guidance path. They were based on the detection of a magnetic field generated by a low frequency signal. The wires were buried in the field several inches below the surface. Rushing (1971) developed a steering system for a tractor to follow a series of electrically-excited buried cables in the field using a steering sensor to detect the signal from the buried cable. The cables were put into the ground to a depth between 61 and 76.2 cm (24 and 30 inches), and excited by a frequency of 2800 Hz supplied by a 100 watt amplifier. The sensor was mounted on a pivot to the front axle of the tractor and kept at the same angle with the centerline of the tractor. The steering sensor consisted of two identical coils. If the sensor

was exactly over the buried cable, equal voltage was induced in each of the coils. If the sensor was to the left of the buried cable, the right coil had higher voltage than the left coil. An electric motor was used to turn the wheels of the tractor until there was no difference between the voltage values of the coils. The motor was replaced with an electrically operated hydraulic valve in the tractor's steering system in a later system development. Accuracy and repeatability for the system were observed to be 2.5 cm (1 inch) at speeds up to 9.6 km/h (6 mph).

Young et al. (1983) evaluated the performance of a vehicle guidance controller by operating a tractor over three different paths (a straight line, a step function, and a sine wave) at various speeds and measuring the resulting guidance response and accuracy. The vehicle guidance controller used an antenna mounted on the tractor to sense the location of an electrically excited wire buried beneath the ground. When a positional error was detected, the correct steering action was performed using the hydraulic steering system of the tractor. Two algorithms, NSD (Not Speed Dependent) and SD (Speed Dependent), were developed to instruct the computer to compute the proper steering response for the tractor. The two algorithms differed in determining the time interval at which the steering rate was incremented when an error persisted. It was constant over all ranges of forward speed in the NSD algorithm, and was dependent upon the forward speed of the tractor in the SD algorithm. The tractor speed was the major factor affecting the steering accuracy for both algorithms. The performance of the NSD and SD algorithms was the same over the range of speeds tested for the straight line and the sine wave tests. The step function tests indicated that the performance of the SD algorithm was better at higher speeds than the NSD algorithm.

A powerful new technology for tractor guidance is a machine vision system that can deduce three dimensional visual information present in the environment and provide meaningful information to a computer. The main applications of machine vision systems can be found in robot guidance and control, part sorting, inspection, gaging, and process control. Two main tasks of machine vision systems are electro-optical imaging (converting optical radiation to an appropriate electronic signal for input to the computer) and image processing (extracting useful information from an electronic image provided by the sensor) (Pinson, 1986).

Reid and Searcy (1987) developed an automatic tractor guidance system using computer vision. The computer vision system was composed of a camera mounted on the front end of the tractor. Image data was recorded with the tractor driving on nearly straight row crops. At the camera the image was a gray level representation. It was thresholded to find a boundary that separated the plant canopy and soil background and form a binary image. The binary image was further processed to compute the tractor guidance signal for row crop operation. The guidance signal for the tractor was composed of angular and positional error components, defined as heading error and offset error, respectively. The heading of the tractor was a function of the relationship between the camera and the parallel crop rows in the field. The offset error was the displacement of the tractor centerline or the camera to the right or left of the guidance directrix.

Brandon and Searcy (1990) designed a vision based tractor guidance system to guide an agricultural tractor in a row crop environment. The vision system sampled the image plane, analyzed the data and provided guidance parameters necessary to steer the tractor. A