Electronically Controlled Towing Bar between Agricultural Vehicles

Dipl.-Ing. Xi Zhang[1], Prof. Dr.-Ing. Marcus Geimer[1], Dipl.-Ing. Ludwig Grandl[2], Dr. agr. Patrick O. Noack[3], Bernd Kammerbauer[3]
[1]Intitute of Vehicle Science and Mobile Machines, Karlsruhe Institute of Technology
[2]AGCO Germany, Marktoberdorf, Germany
[3]geo-konzept GmbH, Adelschlag, Germany

Abstract

This paper presents a method to develop an electronically controlled towing bar system, which will enable an autonomous agricultural vehicle to follow a leading tractor with a given lateral and longitudinal offset. In our study not only the follow-up motions but also the problems such as avoiding obstacle, turning at the end of the field have been considered. With the aid of the RTK GPS systems the position of the leading tractor can be obtained with accuracy in the range of centimetres. The position points of the leading tractor are transmitted by wireless modems to the following vehicle continually to provide the target position points for the guidance of the following agricultural vehicle. With the method of curve fitting a desired path for the following vehicle could be dynamically created. Based on the target position points and the path planning, the desired speed and the desired steering angle of the following tractor are calculated. In order to ensure the precise navigation of the driverless following tractor, a course tracking controller and a speed controller have to be designed and implemented. In addition to path tracking methods, considerations about safety of the towing bar system will also be issued in this paper. The whole research work is supported by the Federal Ministry of Food, Agriculture and Consumer Protection of the German Government.

Keywords
GPS Navigation, Machine Guidance and Control

1 INTRODUCTION

The agricultural farming industry is facing significant challenges at present. The global competition for a higher productivity in the agriculture has made demands on more cooperation between agricultural machines. The decreasing number of farming labor force and higher labor costs in the agricultural industry is a significant issue for the European agriculture. As a response to mechanized farming, more and more GPS-guidance is utilized in modern farming to meet the demands on precision agriculture and has made possible to guide the agricultural vehicles autonomously.

In the past ten years, many research works have been carried out to develop an automated agricultural vehicle to replace the labor workforce in the farming operation. In [1] an automatic steering system was developed to guide a John Deere 7800 tractor along prescribed straight row courses with an average error of approximately 2 cm. In [2] a robot tractor was developed based on RTK-GPS and gyroscope to provide navigation information for the path tracking. Such field robot with auto-steering systems are capable of steering along target lines automatically, but the application of such autonomous agricultural vehicles can only be confined to a laboratory environment, where obstacles and other safety related problems could be foreseen.

To solve the safety problems in the real field operations many other high-tech sensors have been used to sense the surrounding environment of the farming vehicles. In [3] a machine vision based guidance system was demonstrated for an autonomous agricultural small-grain harvester using a cab-mounted camera. In the recent years laser or laser radar (ladar) have been more and more applied in autonomous vehicles to detect obstacles for the safety reasons. In [4] ladar has been used to navigate a small robot tractor through an orchard field. However most of the solutions have been successfully realized only in laboratory conditions. Field trials demonstrated that an automatic guided agricultural vehicle could assist the operator but could not completely replace the operator because of safety considerations. Some solutions which have been proved robust in field tests were very costly and still a long way from commercialization.

On such a background an electronically controlled towing bar system can be regarded as an intermediate step on the road to completely autonomous agricultural vehicles. Because of the presence of the operator on one of the agricultural vehicles, the safety problem can be easily resolved without consideration of costly sensors and complicated sensor fusion algorithm. The primary objective of this paper is to introduce a method to develop an electronically controlled two-tractor towing bar system, which will enable one unmanned tractor to follow up another leading tractor with a given lateral and longitudinal offset. This system can allow one operator to utilize more than two agricultural machines simultaneously, so that the productivity of the working process will be substantially improved and the competitiveness of the agriculture producer will be enhanced.

2 EQUIPMENTS AND METHODS

Figure 1: Fendt 936 Vario tractor and its cabin with Trimble navigation monitor

Fig. 1 shows one of the experimental agricultural vehicles, which was used to compose the towing bar system. The leading vehicle as well as the following vehicle is a 265 kW four-wheel drive Fendt 936 Vario model which is 5.65 m long, 2.75 m wide and 3.37 m high. The equipment used to measure the tractor position of the leading tractor is different from the following tractor. The leading tractor uses a Trimble navigation system, which was mounted by the geo-konzept GmbH. With the AgGPS 252 GPS-receiver attached to the roof of the cab and the 450 radio equipment which receives the real-time kinematic (RTK) signals at 2 Hz data throughput rate, the position accuracy is less than 2.5 cm. Using data from the GPS receiver and internal sensors the position data can be further corrected by the navigation controller in the cab which can compensate the roll, pitch and yaw movement of the vehicle during measurement.

In the following tractor an auto-guide system was already installed to measure the position of the vehicle. This system is an accessory equipment of the Fendt 936 Vario tractor and can correct the positioning error caused by the inclination of the ground. A gyroscope is also integrated in this auto-guide system, so that the positioning can reach the same accuracy as the Trimble system. Both tractors are equipped with an industrial computer which connects the GPS measurement unit and the tractor control unit. The industrial computer "AutoBox" is composed of a PowerPC 750GX processor board running at 1 GHz and several peripheral boards, which can communicate with external equipments over controller area network (CAN) or serial interfaces. With the real-time operating system running on the PowerPC, the AutoBox performs data collection, condition monitoring and control signal

computations using software written at the Karlsruhe Institute of Technology.
In Fig. 2 a method to design a towing bar system for two tractors is demonstrated. A virtual towing bar is used here to demonstrate vividly the relationship between a leading tractor and another unmanned agricultural machine, which follows the leading one. Both vehicles will receive GPS signals to obtain their positions and a path segment (red) to guide the unmanned vehicle will be calculated from the trajectory of the leading tractor (blue) with a longitudinal and a lateral offset. The path segment to guide the unmanned vehicle will be transferred from the leading tractor to the following one periodically using wireless communication. A tolerance zone with a preset width and length is conceived to restrain the following tractor from colliding to the leading one.

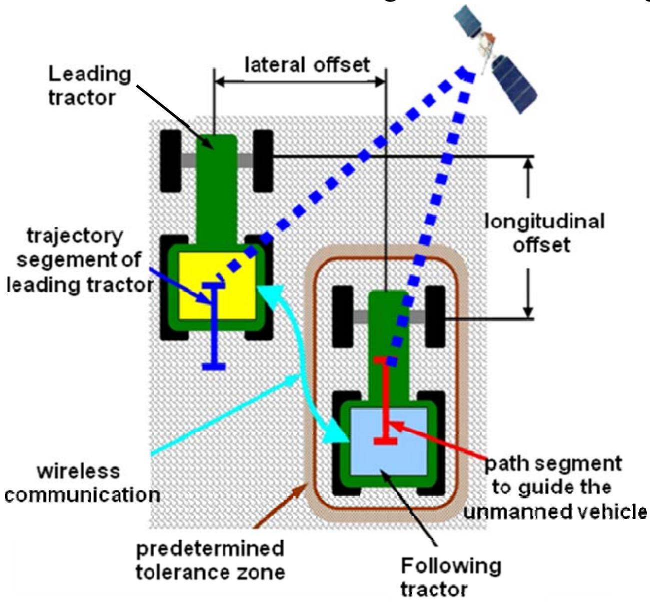

Figure 2: Schematic diagram of the towing bar system for two tractors using GPS navigation and wireless data exchange.

To construct such a two-tractor towing bar system the whole work will comprise four different aspects: an algorithm to create the desired course for guidance of the following vehicle; a path-tracking controller to guide the unmanned vehicle along the desired path; a wireless connection between the two tractors to ensure a real-time data-exchange between the vehicles and to coordinate the work between those; a program monitoring the running conditions of the unmanned vehicle to meet the safety demands.

3 REFERENCE COURSE GENERATION

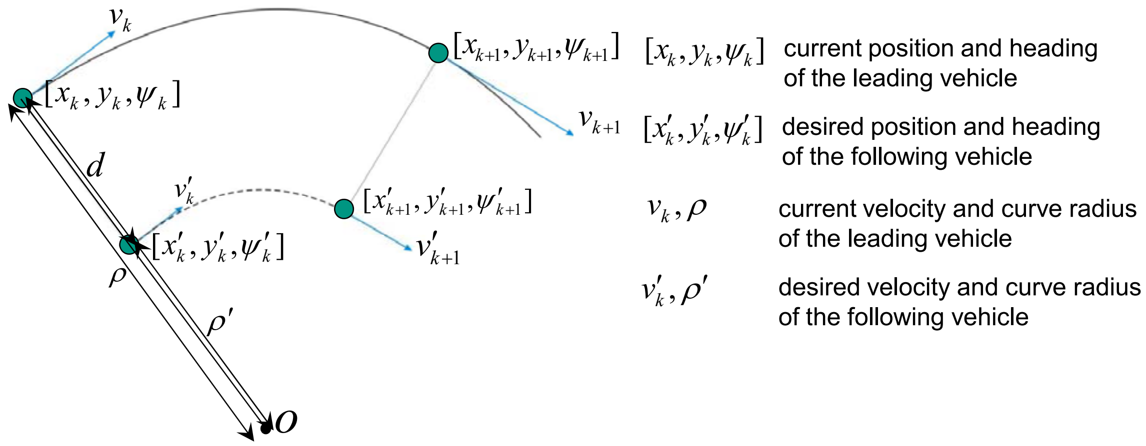

Figure 3: Trajectory of the leading tractor (solid curve) and desired reference course for the following tractor (dashed curve)

The desired reference course to guide the unmanned tractor was calculated using the position data obtained from the GPS measurements on the leading tractor (Fig. 3). The solid curve, which is composed of a seires of position points, refers to the trajectory of the leading tractor. On the other hand the dashed curve which is composed of a series of mapping points, refers to the reference course of the following tractor. The mapping points is on the normal of the solid curve at the current positions of the leading tractor with a lateral offset of d. Point O is the common instantaneous turn center of the leading and the following tractor. The desired vehicle speed for the following tractor will be determined according to its turning radius and the current speed of the leading vehicle.

4 PATH TRACKING

A control structure which contains cascade controller with feed forward control is designed to guide the unmanned tractor along the calculated desired path and to minimize the path error [5]. Fig. 4 demonstrates the structure for the speed control which will adjust the velocity of the following vehicle to keep its distance from the leading tractor constant.

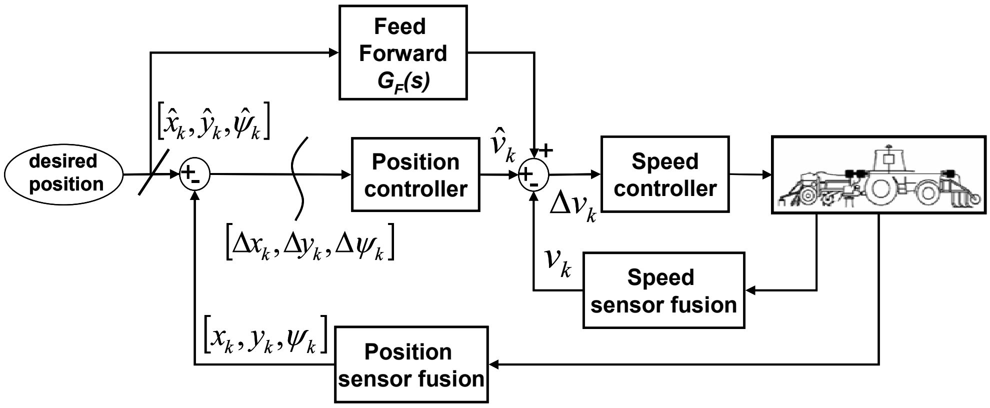

Figure 4: Structure of the cascade controller with feed-forward control for the following vehicle speed.

The structure for the steering angle control is similar to the structure explained above. In this case the position controller will be replaced by a yaw-angle controller, while the speed controller will be replaced by a steering angle controller.

5 WIRELESS COMMUNICATION

5.1 Hardware

One of the most important prerequisites for an electronic controlled towing bar system is that the leading and the following vehicles are connected by a so-called wireless CAN-bridge, which can collect the data from the controller area network (CAN) bus in one vehicle, transmit it over the air and send the information again to the CAN bus in the other vehicle. Because of the normally large acreage of a farm, a wide-coverage mobile communication device with real-time link ability must be chosen to satisfy the requirements for such an inter-vehicle communication [6].
For the radio interfaces the XBee-Pro wireless module from the company Maxstream serves as an IEEE 802.15.4 standard compliant chip. It operates at 2.4 GHz of the ISM radio band and can reach a theoretical data throughput of 250 kbps. Its large band width is sufficient for the transmission of all the navigation and control data defined in our data protocol every 100 milliseconds. With an outdoor range of 1.6 km, it enables a robust point-to-point connectivity in the line of sight.

5.2 Data Protocol

A data protocol, which defines the data type and frame format for all the information to be transmitted by the wireless module, has been created to distinguish communication data with different content and different priorities.

In Table 1 the position data of the leading vehicle is defined in a data frame with 32 bytes and with a frame identifier (frame-ID) of 2. Its frame-ID indicates that this information has a relative higher priority in the whole data list. That reflects apparently the fact that the position data is very crucial for the safety of the following tractor. Without this information, the unmanned vehicle could not be guided correctly and there would be collision danger.

Table 1: data protocol which contains the position and motion information about the leading vehicle

Field	Delimiter	Frame-ID	UTC	Longitude	Latitude	Heading	Speed	Direction	Date
Bytes	1	1	4	6	6	2	2	2	4
Data	0xFF	0x02	xxxx	xxxxxx	xxxxxx	xx	xx	xx	xxxx

Delimiter: Check byte for the start of the frame
Frame-ID: Identification for the data frame, 2 stands for the position data frame from the leading vehicle to the following one
UTC: Coordinated Universal Time
Longitude: Longitude of the current position of the leading vehicle
Latitude: Latitude of the current position of the leading vehicle
Heading: Angle where the leading vehicle is pointing compared to the true north
Speed: Velocity of the leading vehicle
Direction: Direction in which the leading vehicle are moving
Date: Date when the GPS information is recorded

6 SAFETY RELATED CONSIDERATIONS

A vital part of an autonomous, unmanned vehicle is safety. In such a towing bar system, the presence of the operator enhances the safety of the system in unexpected dangerous situations. To disburden the operator from the routine supervising work and assist him by decision making, programs doing condition monitoring have been integrated in the software.

One of the most important system monitoring is the distance monitoring. A virtual rectangle safety zone, which surrounds the unmanned following tractor during its moving, is conceived to constrain the movement of the tractor and to prevent it from colliding against the leading vehicle (see Fig. 2). When the following tractor goes beyond the constraints determined by this safety zone, it will be halted by a real-time program, which will steadily monitor the position of the unmanned vehicle.

Another safety related factor in the towing bar system is the wireless connection between the two tractors. A real-time thread in the system monitoring software sends periodically an “Alive” signal from the leading tractor to the following one. Absence of such information is indicative of a interrupt of the wireless connection and the real-time thread will halt all operations on the following tractor.

As a backup of the supervising software the operator can trigger the emergency stopping to halt the following vehicle immediately in unexpected dangerous situations.

7 EXPERIMENTAL RESULTS

Verification tests were conducted on both asphalt and farm fields. The trajectory tracking results from a farm field test is shown in Fig. 5. In this test, the trajectory of the leading tractor was measured by the Trimble navigation system and transmitted through the wireless communication to the following tractor. This information as well as the information about the following tractor itself were recorded by CAN monitoring software and demonstrated in a UTM-coordinates-based map as shown in Fig. 5.

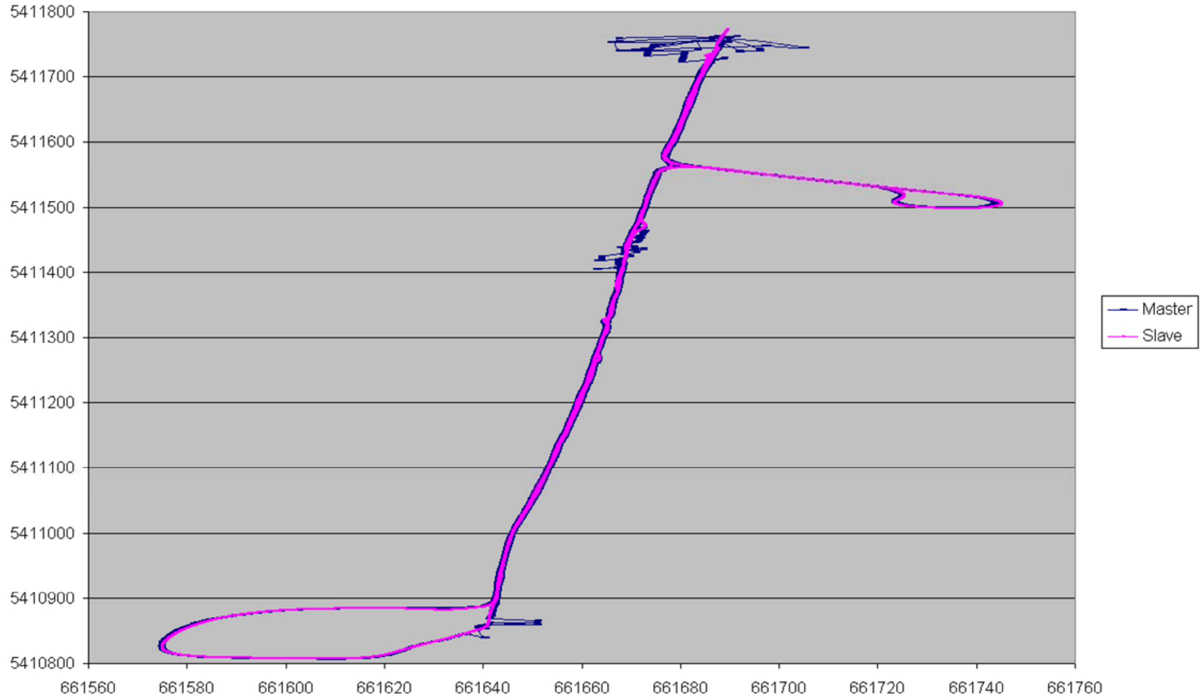

Figure 5: Tracking results from a field test

The results showed that the lateral deviation was less than 0.1 m on most of the path trajectories. Larger deviations exist only on the path trajectories where inaccurate position measurements of the master vehicle were taken.

8 CONCLUSIONS

In this paper we presented an approach for developing a towing bar system for agricultural vehicles, which is able to automate an unmanned agricultural vehicle to fulfil some agricultural task, such as plowing and drilling, cooperatively with another leading tractor. Compared with other autonomous agricultural robots which are still far from commercialization, the experimental prototype will be able to be converted in a commercialized product in the near future. An interesting and novel facet of this research is the tolerance zone which constrains the movement of the autonomous vehicle. Significant challenges still lay ahead to determine the dimension of this tolerance zone and to control the unmanned vehicle accurately so that it can always stay in this tolerance zone. Another advantage of our proposal is the supervision of the operator as a safety back-up of the system. Preliminary results from our computer simulation have shown that the following vehicle can follow the leading one satisfactorily.

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REFERENCES

[1] M. O'Connor, T. Bell, G. Elkaim, B.W. Parkinson "*Automatic steering of farm vehicles using GPS*" in Proceedings of the Third International Conference on Precision Agriculture, Minneapolis, MN, June 23-26, 1996, pp.767-778.

[2] N. Noguchi, J.F. Reid, Q. Zhang, J.D. Will, K. Ischii, 2001. "*Development of robot tractor based on RTK-GPS and gyroscope*" ASAE Paper 01-1195.

[3] E.R. Benson, J.F. Reid, Q. Zhang, "*Machine vision-based guidance system for agricultural grain harvesters using cut-edge detection*" Biosystems Engineering, vol.86, no.4, pp.389-398, 2003.
[4] R. Tsubota, N. Noguchi, A. Mizushima, "*Automatic guidance with a laser scanner for a robot tractor in an orchard* " in Proceedings of the Automation Technology for Off-Road Equipment Conference, Kyoto, Japan, 2004.
[5] Y. Gao, Q. Zhang "*A Comparison of Three Steering Controllers for Off-road Vehicles*" in Proceedings of the Automation Technology for Off-Road Equipment Conference, 1-2 September 2006, Bonn, Germany, pp.289-301.
[6] N. Murakami, A. Ito, J.D. Will, M. Steffen, K. Inoue, K. Kita, S. Miyaura "Development of a teleoperation system for agricultural vehicles" Computers and Electronics in Agriculture, vol. 63, 2008, pp. 81-88.

Contact:
Dipl.-Ing. Xi Zhang,
Institute of Vehicle Science and Mobile Machines, Karlsruhe Institute of Technology,
Fritz-Erler-Str. 3, D-76131 Karlsruhe, Germany
phone: +49 (0721) 608-8640
fax: +49 (0721) 608-8609
Email: xi.zhang@kit.edu