**Zhang, Xi; Geimer, Marcus; Grandl, Ludwig; Ehrl, Markus and Noack, Patrick**

# Electronic towing bar system for agricultural machines

This paper presents an electronically controlled towing bar system, which will enable a driverless agricultural vehicle to follow a leading tractor to accomplish the same farming process. Considered have been not only the follow-up motions with given lateral and longitudinal offsets but also the problems such as avoiding obstacle and turning at the end of the field. With the aid of RTK-GPS-systems the position of the leading tractor was determined in order to calculate the desired course for the following one. A tracking controller was responsible for an accurate guidance of the driverless following tractor along the desired course. Considerations about the safety of the whole towing bar system were issued in this paper, too.

**Kewords**

GPS navigation, machine guidance and control

**Abstract**

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The global competition for a higher productivity in the agriculture has made demands on more improvement in efficiency through the automation of agricultural working processes. Among other things the cooperation between agricultural machines during the working processes must be developed. With regard to these facts more and more GPS-guidance is being 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. 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 high-tech sensors have been used to sense the surrounding of the farming vehicles. In [3] a machine vision based guidance system was demonstrated for an autonomous agricultural harvester using a cab-mounted camera. In the recent years laser or 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. In the following the method to develop such a towing bar system for agricultural machines will be presented. Based on two commercial tractors, which are coupled with each other by wireless communication, the unmanned tractor can follow the leading one with given lateral and longitudinal offsets and do the same job in the field.

## Equipments and Methods

**Figure 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. With the AgGPS 252 GPS-receiver attached to the roof of the cab and the 450 MHz radio equipment which receives the real-time kinematic (RTK) signals at 1 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 a proprietary navigation 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 **figure 2** a method to realize the tow-bar system for two tractors is demonstrated. A virtual tow-bar like coupling is used here to demonstrate vividly the relationship between a leading tractor and another unmanned agricultural machine, which follows the leading one. To establish this coupling a special controller has to be developed, which will be added to the existing control system of the tractor. The leading tractor receives its position data from the GPS satellites and sends it to the following one over a wireless data link. The position information of the leading tractor will be then used for the path planning on the following one

To construct such a two-tractor towing bar system the whole work will comprise four different aspects:

- an algorithm doing the path planning for 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.

## Path Planning

The desired course for the unmanned tractor was calculated using the position data obtained from the GPS measurements on the leading tractor (**figure 3**). The solid curve refers to the trajectory of the leading tractor. The mapping points on the dashed curve locate on the normal of the solid curve and follow the 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 $v'_k$ will be determined according to its turning radius $\rho'$ and the current speed of the leading vehicle $v_k$. Not only the standard mode, in which the unmanned tractor follows the leading one with a give offset, but also the situations such as obstacle avoidance and turning at the field's end were considered in our work.

## 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]. **Figure 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. 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.

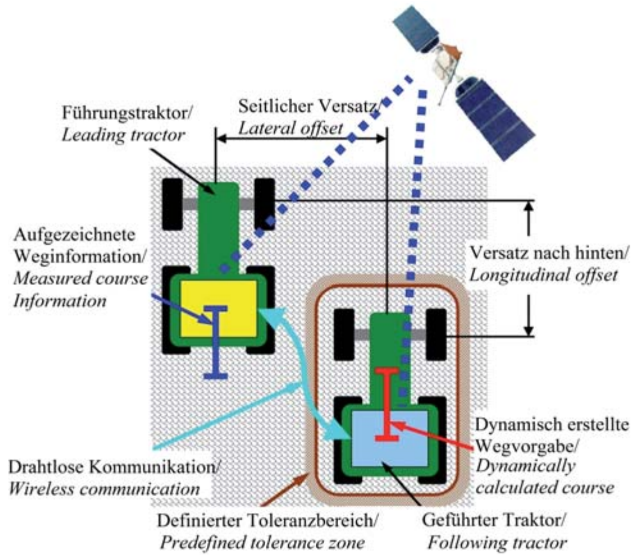
## Wireless communication

Hardware: One of the most important prerequisites for an electronic tow-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 informa-

Fig. 1

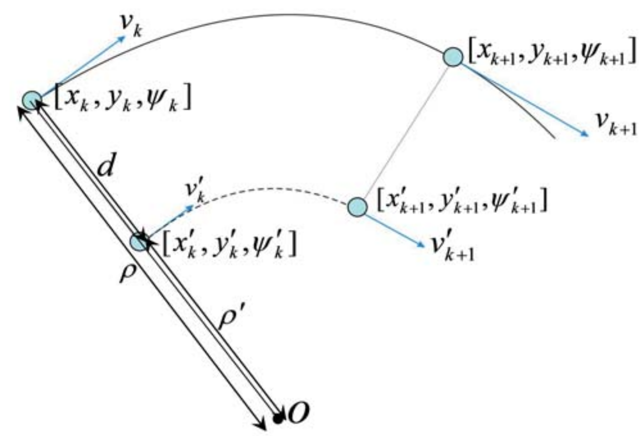

*Fendt 936 Vario tractor and its cabine with navigation monitor from Trimble*

Fig. 2




*Diagrammatic depiction of the electronic towing bar between the two tractors using GPS and wireless data exchange*

Fig. 3



| | |
|---|---|
| $[x_k, y_k, \psi_k]$ | Aktuelle Position des Führungsfahrzeugs/ *Current position of the leading vehicle* |
| $[x'_k, y'_k, \psi'_k]$ | Gewünschte Position des geführten Fahrzeugs/ *Desired position of the following vehicle* |
| $v_k, \rho$ | Aktuelle Geschwindigkeit und der Kurvenradius des Führungsfahrzeugs/ *Current velocity and turning radius of the leading vehicle* |
| $v'_k, \rho'$ | Gewünschte Geschwindigkeit und der Kurvenradius des geführten Fahrzeugs/ *Desired velocity and turning radius of the following vehicle* |

*Trajectory of the leading tractor (solid curve) and desired course for the following tractor (dashed curve)*

tion 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]. As radio interfaces we have chosen the XBee-Pro wireless module from the company Maxstream, which has 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 signals 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.

Data Protocol: A data protocol, which defines the data type and data structure for all the information to be transmitted by the wireless module, has been created. 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.

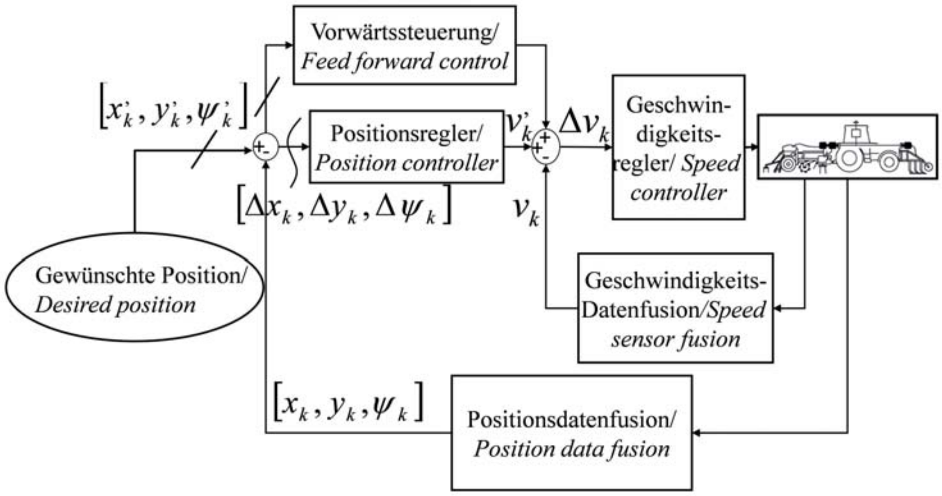
## Safety concepts

A vital part of an autonomous vehicle is safety. In such a towbar system, the presence of the operator enhances the safety of the system in unexpected dangerous situations. With the aid of an additionally developed control panel including digital display one can keep his supervision of the unmanned tractor continually. 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. As a backup of the supervising software the operator can always trigger an emergency stop to halt the following vehicle immediately in unexpected dangerous situations. The driver on the leading tractor will be directly warned about a safety critical situation, if the wireless link between the two tractors is disconnected or the distance between the two tractors is too little.

In the leading tractor there is a feedback system in respect of wireless link between the two machines. 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 an interrupt of the wireless connection and the real-time thread will halt all operations on the following tractor.

One of the most important aspects of the safety concept is the distance monitoring between the leading and the following machines. A virtual tolerance zone is defined around the unmanned vehicle preventatively, so that a short-time transmission error over the wireless link doesn't arouse any safety problems and the driving course can still be interpolated, as long as the unmanned vehicle remains in this tolerance zone (see **figure 2**). This tolerance zone is calculated based on the navigation data from the leading tractor. If the following tractor goes beyond the tolerance zone, it will be halted by a real-time

Fig. 4




*Structure of the cascade controller with feed forward control for the speed regulation*

program, which will steadily monitor the position of the unmanned vehicle.

## Experimental results

Verification tests were conducted on both asphalt and farm fields. The trajectory tracking results from a farm field test is shown in **figure 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. 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.

## Conclusions

With the approach we presented before we have managed to automate an unmanned agricultural vehicle to fulfil agricultural tasks, such as ploughing and drilling, cooperatively with another leading tractor. Compared with other autonomous agricultural robots which are still far from commercialization, the developed system has been tested on two prototypes and will be further developed. An interesting and novel facet of this research is the tolerance zone which monitors 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. Results from both our computer simulation and the field tests have shown that the following vehicle can follow the leading one satisfactorily.

## Literature

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Table 1

*Data protocol for the position and motion information about the leading machine*

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

Delimiter: Anfangsbyte des Frames/*Check byte for the start of the frame*

Frame-ID: Identifier des Datenframes, 2 steht für Positionsdaten/*Identification for the data frame, 2 stands for the position data frame*

UTC: Koordinatenuniverselle Zeit/*Coordinated universal time*

Longitude: Langsgrad der aktuellen Position des Führungstraktors/*Longitude of the current position of the leading vehicle*

Latitude: Breitengrad der aktuellen Position des Führungstraktors/*Latitude of the current position of the leading vehicle*

Heading: Winkel zwischen der Bewegungsrichtung des Fahrzeugs und Nord/*Angle where the leading vehicle is pointing compared to the true north*

Speed: Geschwindigkeit des Führungstraktors/*Velocity of the leading vehicle*

Direction: Bewegungsrichtung des Führungstraktors/*Direction in which the leading vehicle is moving*

Date: Datum, an dem die GPS-Informationen aufgezeichnet werden/*Data when the GPS-information ist recorded*

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## Authors

**Dipl.-Ing. Xi Zhang** is research assistant on the Chair of mobile Machines, Karlsruhe Institute of Technology (Head: **Prof. Dr.-Ing. Marcus Geimer**), Gotthard-Franz-Str. 8, 76131, Karlsruhe, E-Mail: xi.zhang@kit.edu

**Dr. agr. Patrick O. Noack** works at the company geo-konzept and he is responsible for the distribution of the GPS-systems and the development of customer-specific GI-systems.

**Dipl.-Ing. Ludwig Grandl** works at the AGCO Company in Marktoberdorf and works on this research project in the department „R&D Electronics“.

**M.Sc. Dipl. Wirt.-Ing. Markus Ehrl** works at the AGCO Company in Marktoberdorf and he is responsible for the development of ISOBUS and VarioDoc in the department „R&D Electronics“.

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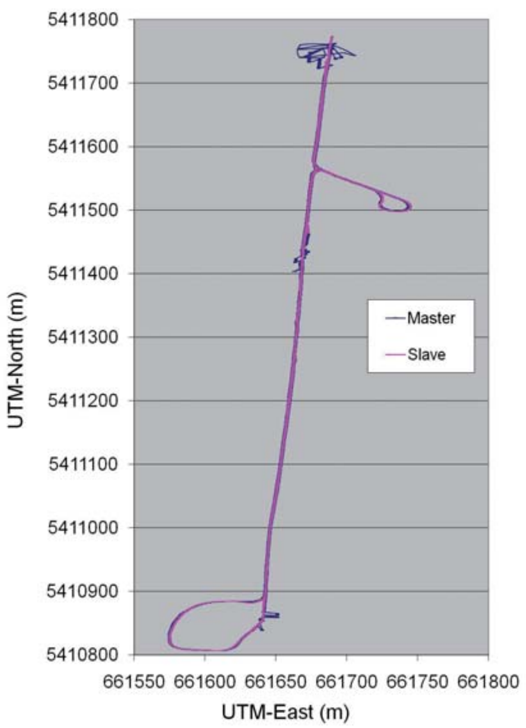
Fig. 5




*Tracking results from a field test*