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Improving safety of an electronic draw bar system for agricultural machines

The market for increasingly powerful agricultural machinery appears to be steadily growing. Operating two tractors being coupled by an electronic draw bar, the affectivity per qualified operator almost doubles in the field. Productivity and the capacity load improve due to more flexible scheduling. In the current research project, an unmanned following tractor is equipped with environment sensors and connected to a geo-information server via a mobile internet modem. This way, obstacles can be detected and optimal paths for obstacle avoidance can be calculated. As a result, safety improves and the driver of the leading tractor is being relieved from supervising the unmanned following vehicle.

Keywords
Electronic draw bar, autonomous driving, environment sensors, geo informations

Abstract
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Modern agriculture is progressively drawn into a major structural change with complex dependencies. Due to the opening of agricultural markets for international trading decades earlier, the relation between production costs, demand and market prices can no longer be called trivial [1]. Since the 1950s, increasing cost pressure enforces expanded farm consolidation leading to enlarged fields to be tilled and a reduction of the number of agricultural employees [2; 3].

The agricultural machinery companies proved themselves to be capable of meeting the requirements by a steady rise of the motor power and consequently a significant gain of machine productivity. After liberalization of the American global satellite navigation system (GPS) for civil use in 1996, agricultural machinery manufacturers presented diverse electronics and IT-innovations, i.e. harvest mapping, precision farming and not at least driver assistance systems to improve the productivity per acre, the process efficiency and the driver's comfort. Today's research projects such as iGreen [4] also focus on the connectivity and networking between machines and offices in an overall agricultural context.

The steady increase of machine power cohering with sizes and weight already outbids the legal limits in many European countries.

Therefore the Chair for Mobile Machines (Mobima) of Karlsruhe Institute of Technology (KIT) in cooperation with geokonzept GmbH and AGCO GmbH is involved and promoting the research project Electronic Drawbar for Agricultural Machines (EDA, terminated in 2010 [5-7]) since 2007. The current follow-up project Electronic Drawbar for Agricultural Machinery with Environment Sensors and Additional Geo information (EDAUG) applies sensors and IT to further increase the effective machine power in field on a different way.

Virtually docking an unmanned tractor (slave) to a manned tractor (master) offers the possibility to run tillage processes with double machine power without additional human driver. The tractor platoon as developed in the EDAUG project is equipped with environmental sensors and an internet connection to a geo information server at runtime. This allows intelligent automatically calculated obstacle avoidance maneuvers, using geo information data for efficient path planning and supports safe guidance of the unmanned tractor.

Background of the EDAUG project

During the preceding EDA project, the concept for an electronic drawbar system for tillage processes with parallel driving tractors has been developed and the feasibility has been proved on a prototype test platoon. A safety concept and path planning algorithms have been developed for the wirelessly connected tractors, to be operated in common tillage processes.

In the default driving mode Parallel Driving the slave tracks the master tractor with a preset lateral and longitudinal offset, the implement being fully operational. The driving modes Tracking and Follow can be activated to evade obstacles either on the slave or master path, not affecting the track of the other platoon vehicle. A turn-over algorithm controls the turn-over maneuver meeting the driver's commands as well as the constraints of the tractor's turn radius limits with attached implement [5].

To guarantee safety in case of system malfunctions, the communication between the platooning vehicles, the GNSS signal quality, the control offset of the actual slave position as well as critical vehicle parameters are permanently monitored.

Compared to the guidance of only one tractor, the guidance of such a drawbar system is highly demanding for the driver. However the driver is eventually responsible for the accident free operation of both vehicles. Therefore, the main objective of the research project EDAUG is to improve overall safety and the driver's relief.

Safety concept for an electronic drawbar system with obstacle detection

Operation of tractors coupled by an electronic drawbar system causes additional risks for persons, the environment and the machines to evolve. Hence, static and dynamic obstacles need to be reliably detected to initiate appropriate collision avoidance measures. While the driver was in charge of both, observation and decision, the EDAUG-slave is carrying environment observation sensors and is linked to a geo information server (GIS) to detect obstacles early, to calculate avoidance paths, to give a warning or if necessary to activate a safe system state autonomously.

Safety concept

The system behavior is based on a four level safety concept, which is designed to meet the requirements of safety, usability, driver responsibility and in field productivity (**Table 1**). In Default state and Warning state the user level system behavior is not affected. In Warning state alerts can encourage the driver, to avoid critical driving scenarios by preventative measures. The activation of Safety Stop or Emergency Stop is carried out without interaction with the driver and triggers a distinct change of the tractor behavior. A risk analysis of the EDAUG drawbar results in the requirement, that these two autonomously activated system states must not procreate any additional risks or dangers for persons and environment under any circumstances.

Table 1

Zustände des EDAUG-Sicherheitskonzepts
Table 1: States in the safety concept of the EDAUG system

Zustand/*State*	**Auslöser/*Trigger***	**Maßnahme/*Action***
1. Normalzustand ***Default State***	• Keine Risiken oder Fehler sind bekannt. *No risks or errors known.*	• Keine Maßnahme erforderlich *No actions necessary.*
2. Warnung ***Warning***	• Ein unkritischer Maschinenparameter überschreitet auf dem Slave einen Grenzwert; es besteht kein Risiko für Personen, Umwelt oder Maschinen. *Uncritical parameter exceeds limit; no risks for persons, environment or machines.* • Die Umfeldsensorik erkennt ein Hindernis in größerer Entfernung; es besteht kein akutes Kollisionsrisiko. *Obstacle detected by sensors; no urgent risk of collision.* • Der Geoinformationsserver meldet ein Hindernis im geplanten Pfad in größerer Entfernung; es besteht kein akutes Kollisionsrisiko. *Obstacle from geo-information server known in planned path. No urgent risk of collision due to high distance.*	• Der Fahrer wird informiert. *Driver information* • Ggf. wird ein Ausweichpfad berechnet und dem Fahrer vorgeschlagen. *Obstacle avoidance path is calculated and suggested to driver.*
3. Sicherheitsstop ***Safety stop***	• Ein Hindernis befindet sich im Gefahrenbereich des Slaves (Umfeldsensorik und/oder Geoinformation); es besteht akutes Kollisionsrisiko. *Obstacle in danger zone of slave vehicle detected (sensors or geo-information); urgent risk of collision.*	• Die Fahrgeschwindigkeit des Slaves wird schnellstmöglich auf 0 km/h reduziert. *Drive speed reduced to zero.* • Rotatorische Antriebe des Slaves werden angehalten. *Rotary drives are stopped.* • Hydraulikzylinder des Slaves verbleiben in ihrer aktuellen Position. *Hydraulic cylinders remain in current position.*
4. Notaus ***Emergency stop***	• Ein Maschinenparameter auf dem Slave über schreitet einen kritischen Grenzwert. *Critical parameter exceeds limit.* • Die Qualität des GNSS-Empfangs ist unzureichend. *GNSS signal quality too low.* • Die Funkverbindung zwischen den Fahrzeugen ist beeinträchtigt. *Wireless data link interrupted.* • Ein Softwaremodul des Systems erzeugt einen Fehler. *Error in any software module.*	• Der Motor des Slave wird abgeschaltet. *Immediate shut down of slave motor* • Die Feststellbremse wird aktiviert (Anm: Funktion auf den Versuchsschleppern nicht elektronisch durchführbar). *Handbrake is activated (comment: not yet available as X-by-wire-function).*

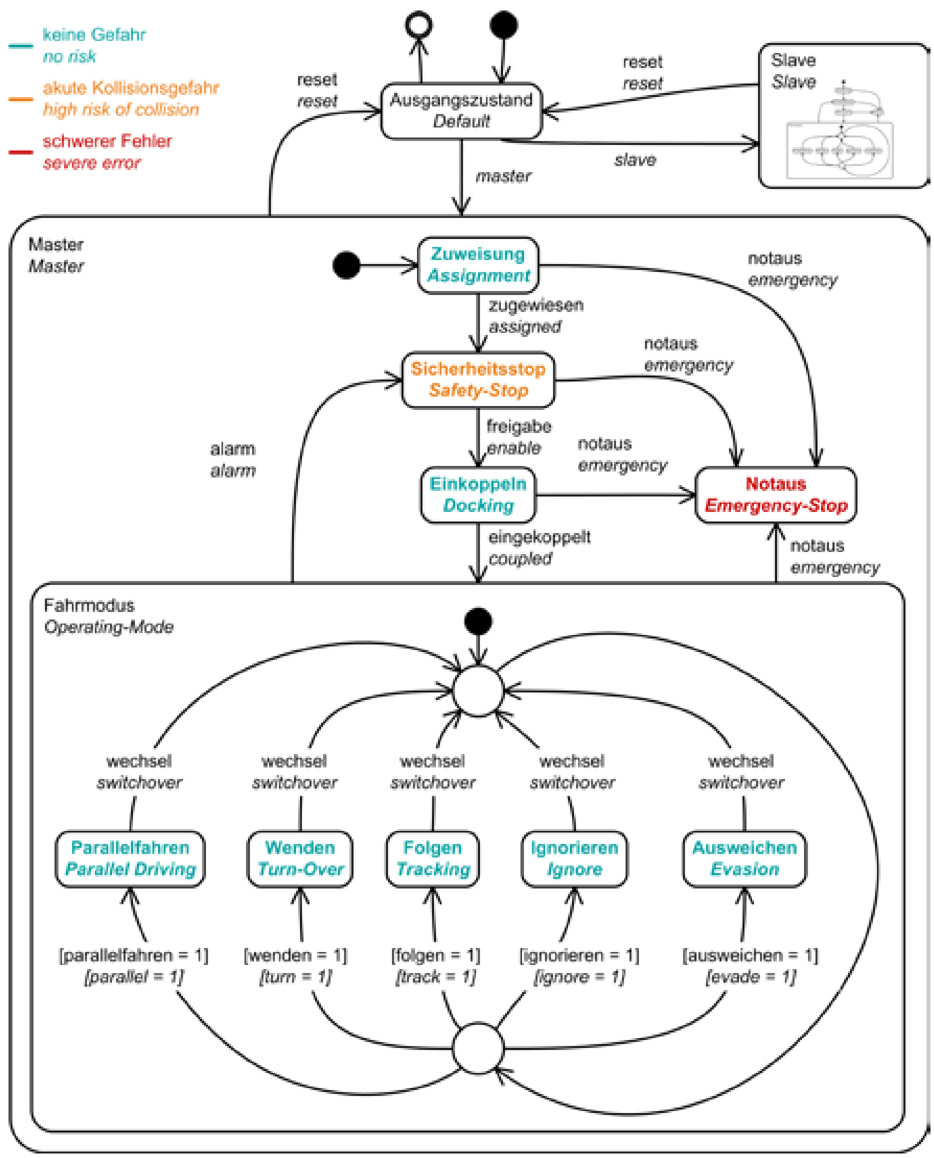
The states of the safety concept are embedded in a state machine, controlling the system behavior of the platoon in runtime.

System behavior

In a state machine, states connected by transition conditions are defined to describe a system behavior by time based or logical sequences. States are characterized by entry actions, during actions being executed as long as the state is active and exit actions. The during action of a state can also include a network of substates. **Figure 1** shows the EDAUG state machine. The transition from one state into a connected other state (arrow) is executed, if a transition condition becomes true (square bracket) or a specified event occurs.

Once, the electronic drawbar mode is selected on a tractor, the EDAUG system starts in the Default state and is ready to be defined as a Master or Slave participant of the platoon. The structures of the substates in Master and Slave state are identical. The overall system state can be denoted valid, if both vehicles of a platoon are in the same active state. Initial to any driving or tillage operation, an initial phase to establish a wireless connection and assign two tractors to each other needs to be accomplished. Once in the state Safety Stop, the Slave can be left on its own. Prior to swapping into Operation-Mode, the driver is in charge to intentionally enable the driving modes via the user interface and a Docking-cycle is being executed in which the validity of the relative GPS position and the relative angular orientation between the vehicles is checked with respect to the preset drive mode (default: Parallel Driving). The Operation-Mode includes the five EDAUG drive modes, composed of the four EDA drive modes and the additional Evasion mode, in which the slave is navigated along an obstacle avoidance path based on static and dynamic real-time obstacle coordinates. Contrary to Safety Stop and Emergency Stop this state cannot be activated autonomously, as additional risks can pos-

Fig. 1



State model of the EDAUG system behaviour sibly evolve on a new path. If an obstacle warning (see safety concept) occurs, the driver is in charge to manually activate the Evasion mode.

The transition leading into Safety Stop can only be performed from Operation-Mode and is superior to the drive mode transitions. The Emergency Stop can be triggered from all states and substates once the vehicle role is set to Master or Slave.

Safety and intelligent path planning based on environment sensors and online geo information

The obstacle detection basically serves two objectives. First of all, obstacles within a defined danger zone surrounding the slave need to be detected reliably. Additionally, the early detection of obstacles enables the calculation of efficient obstacle avoidance paths without stopping the platoon. The environmental sensors as well as the geo information server provide information about the position of obstacles on site of the tractors. As the reliability of geo information cannot be guaranteed – there is no data quality or integrity check; dynamic obstacles are principally not included in geo information data – the safety requirements need to be met completely by the environment sensor concept. However the GIS data may be interpreted and be used for Safety Stop. Besides physical obstacles as bush, towers, poles and water bodies, virtual obstacles as field or tillage borders can be stored in a GIS system and be used for additional safety. The EDAUG GIS obtains its data from diverse web services as well as user teach-ins. The geo-data is then standardized and offered to EDAUG platoons as a customized web service. The surveillance area (**Figure 2**) is divided into a short-range surveillance area (focus safety) and a long-range surveillance area (focus early detection).

An obstacle detection event inside of the long-range surveillance area triggers a warning message on the user interface and initiates the calculation of avoidance paths, while a detection event within the short-range surveillance area triggers the immediate activation of the Safety Stop. The dimensions of the short-range surveillance area are continuously adapted to the slave's driving speed.

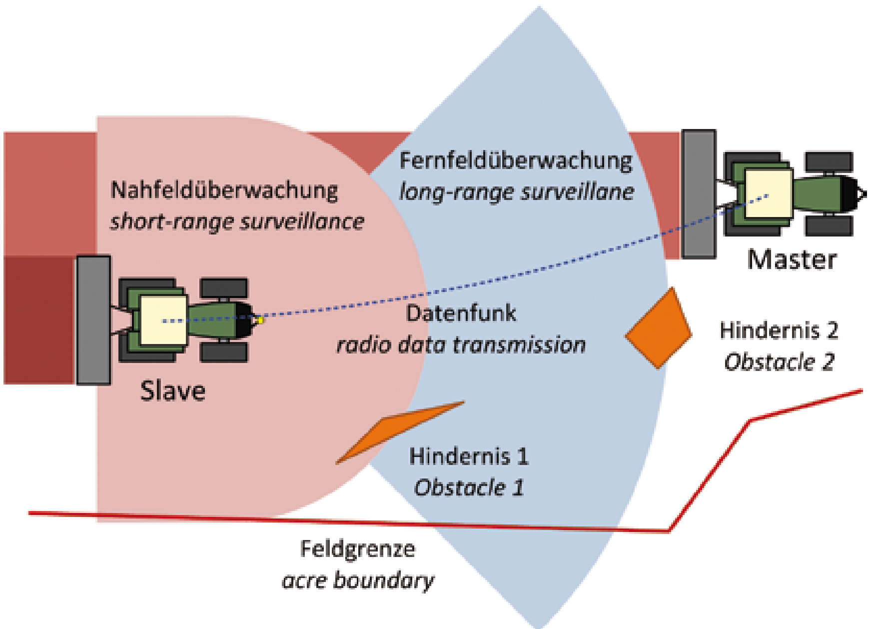
Maneuver control and obstacle management in the user interface concept of the electronic drawbar

The design of the user interface (HMI) is an important part for the project objectives. Besides the settings of functional parameters of the platoon, the driver is informed about the actual ambient awareness of the slave and can control the reaction of the slave in case of obstacles. If an obstacle notification has occurred on the HMI, the driver may chose out of four options:

1. The obstacle exists and shall be considered for navigation
   → transition to Evasion mode
2. The obstacle exists, but shall be ignored
   → system remains in current drive mode
3. The obstacle is not existent, but shall be considered for navigation
   → transition to Evasion mode
2. The obstacle is not existent and shall be ignored
   → system remains in current drive mode

If the driver stays passive, the system will create another notification as soon as the last possible position for an avoidance path is reached. Once the obstacle intrudes the short-range surveillance area, the Safety Stop is triggered, as the Evasion maneuver cannot be activated autonomously.

Fig. 2



Short- and long-range surveillance by slave tractor

Once detected, obstacles are being tracked and stored in a local ambient map until they have been passed safely. The life cycle of an obstacle is protocolled from its time of detection (time of birth) including all interactions with the driver and other system modules. Thereby the system behavior can be retraced afterwards.

Implementation of a prototype platoon and outlook

There are two Fendt 724 Vario tractors available for the project team to implement the EDAUG system. The software moduls are carried out on real-time systems and electronic control units (ECU) by dSPACE and STW, as well as the main ECU of the tractor itself. The user interface is being integrated into the standard Fendt Vario-Terminal. The obstacle detection is based on a sensor fusion concept of 2D-laser scanners and 3D-Time-of-Flight cameras. Furthermore the information gain of a thermal imaging camera in a sensor fusion concept shall be evaluated.

After field tests for code validation of the new state machine and the integration of environment sensors and the geo information server, the EDAUG project will terminate with a final proof of concept of the prototype platoon in March 2014.

Conclusions

The EDAUG project team has developed a concept that allows safe guidance of an unmanned tractor in tillage processes. While the overall responsibility for the two platooning vehicles remains with the driver, the decision to activate safe states during operation can be taken autonomously.

Therefore, the environment sensor data need to be analyzed for ambient obstacle recognition on the slave. A permanent web link providing previously mapped obstacles ensures an user friendly platoon guidance.

The results of the obstacle data analysis are concentrated and presented on the HMI in an intuitive layout, which allows fast comprehension of the actual situation and easy handling of the drive mode control for the slave.

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