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comRoBS – a flexible platform for research on cooperating machinery

Harvesting scenarios are an obvious example for the intensive cooperation of several machines. For research on basic structures of cooperative machine operations the Institute of Agricultural Machinery and Fluid Power (ILF) in Braunschweig has available several autonomous field robots, which have been used to prove the developed strategies and algorithms. A harvesting scenario for a combine as well as for a forage harvester has been illustrated in a first project. In focus of research were: algorithms for the cooperative control of the machines, suitable communication structures, approaches for path planning of several machines on the same field as well as systems for the parallel guidance of a harvester and a transportation unit.

Keywords
Vehicle guidance, communication structures, cooperating machinery, multi machine control, robotic, relative positioning

Abstract
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The increasing automation of single mobile working machines leads to the approach of automating cooperative machine operations, too. To pursue this idea, the Institute of Agricultural Machinery and Fluid Power (ILF) in Braunschweig developed a robot platform and a first application for the research on fundamental relations in cooperative machine operation. In the first part of this essay, the mechanical structure and the sensor and software concept of the robot platform are briefly introduced. The second part deals with the application to implement the cooperative machine operation.

Structure and technology of the comRoBS

The comRoBS (cooperating mobile Robots Braunschweig) have been developed by the ILF and enable both indoor and outdoor operation [1]. The main technical data can be found in **table 1**.

Table 1

Technical specifications of comRoBS

Länge *Length*	600 [mm]	Motorleistung *Engine power*	250 [W]
Breite *Width*	350 [mm]	Antrieb *Drive*	Allrad *4WD*
Leergewicht *Empty weight*	20 [kg]	Geschwindigkeit *Velocity*	max. 5,5 [m/s]
Zuladung *Payload*	max. 20 [kg]	Einsatzdauer *Operating time*	max. 4 [h]
Lenkung *Steering*	Allrad *All-wheel*	Bordspannung *On-board voltage*	24 [V]

Fig. 1

Flexible platform for research comRoBS. Source: ILF

The electronic system of the comRoBS can be divided into a high-level and a low-level section connected via CAN-bus. The computing power of the high-level section is distributed to a MicroAutoBox (by dSPACE) and an Intel Atom-based mini-PC. In the low-level section standardized self-developments, so-called low level boxes, are used, which actuate the hardware and read the sensor data. For the communication between the vehicles the ZigBee wireless network standard is employed, which can be used to exchange control data between multiple robots due to low latencies. A 2-D positioning system (LPR, by Symeo) provides the pure XY coordinates as well as information about heading and speed. For the two-dimensional area coverage a laser scanner (by Sick) is mounted on each vehicle (**figure 1**).

Cooperative machine operation

The comRoBS are used to develop and test algorithms and communication structures for the autonomous cooperation of several machines during e.g. a harvesting process. In a first project the harvesting processes of a combine harvester (sequential overloading) and a forage harvester (continuous overloading) – each with an associated transport unit – were analysed and modelled [2]. This involved the development of a basic multi-machine control strategy for the vehicles as well as necessary communications rules, strategies for the path planning incorporating collision avoidance and methods for the automatic or autonomous parallel guidance while overloading.

Vehicle control

The harvester acts as master vehicle, which transmits relevant information and control commands to the transport unit - the slave. All parameters describing the field are stored centrally on the master and before starting the whole harvesting process they are sent to the slave. Afterwards, the master drives to the first lane to be processed and begins the harvesting. Using fictitious field and machinery parameters as well as the travelled route, a virtual filling level is formed. Similar calculations are used in reverse to determine the time and place at which the tank will be filled completely. This information is sent to the slave, which then calculates its path to the coordinates of the rendezvous and the time to start its approach. Thus in far range both vehicles calculate their paths independently.

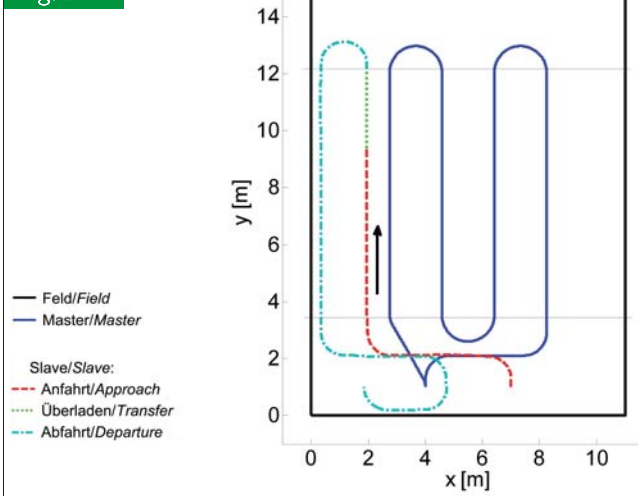
In the close-up range the safe rendezvous is of particular importance. In the last phase of its approach the slave advances the master on a parallel path from behind. Due to its higher velocity the slave overtakes the master and can be detected with the laser scanner of the master subsequently. By recognizing the slave the rendezvous is completed and the master controls the slave until the end of the overloading process. After the complete evacuation of its tanks the master terminates the overloading process and the slave drives back to the headland on its own. There it hands its charge over to another transport unit and is afterwards available for a new approach.

To test the developed algorithms and functions a simulation model had been developed under Matlab/Simulink, in which the comRoBS are modelled as bicycle models. This allows a simple analysis of the whole system behaviour in closed loop and thus early detection and troubleshoot of malfunctions before the actual use on the comRoBS.

Path planning and collision avoidance

The field is divided into the areas “headland” and “field to be processed” regarding the known field geometry, the working width of the harvester and the minimum turning radii of the involved vehicles. For each area a minimum number of possible manoeuvres could be determined from which all paths for the master and the slave can be put together. At the beginning of the harvesting process the master calculates its path to process the field completely. This path is then available for other applications such as collision avoidance. The slave on the other hand calculates its path for each separate approach and departure and can therefore react to changing conditions. **Figure 2** shows an example for a complete path of the master and the according path of the slave for its first arrival and departure.

Fig. 2



Path planning for master and slave

The collision avoidance includes three levels. The paths for the approach and the departure of the slave are placed in such a way that the number of intersections with the known path of the master is reduced to a minimum. If a crossing is unavoidable, the slave needs the release of the critical track section by the master to continue its way. On the second level the vehicle speeds are staggered by the control of the master if both vehicles use similar paths over a longer period of time. The speed of the preceding vehicle is chosen higher than the following and thus collisions are avoided. On the third and lowest level the distance between both vehicles is calculated permanently and below a defined threshold the machines are stopped.

Parallel guidance

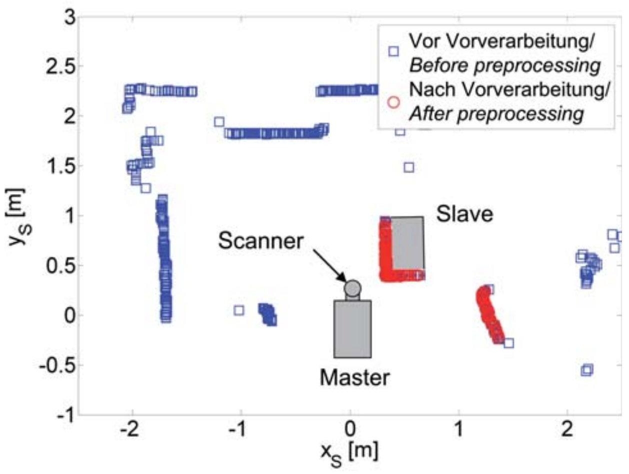
From the moment of the rendezvous to the end of overloading the master controls the slave. To calculate the relative position it uses the laser scanner attached to its front end. In a pre-processing of the scanner data all irrelevant measurement points are excluded. These are, for example, points that are far away from the master and that are not on the current side of overloading. **Figure 3** shows the result in a highly structured environment. In the remaining, red illustrated measurement points straight lines are searched using a split-and-merge algorithm. In the last step the length and relative position of these lines are compared with the known contour of the slave. The relative orientation of the slave and the relative position of its reference point can be calculated if the current data-set contains the slave's contour.

The control commands for the slave are generated using a point tracking method and a longitudinal control. The point tracking method aligns the slave with an imaginary target point, which is located in a specific distance in front of the required position. The speed of the slave results of two shares. First, the theoretical speed of the slave is calculated from the known speed of the master and the current path curvature. Second, the deviation from the target position is calculated continuously and fed to a position controller.

Conclusions

In a first project the comRoBS could be used successfully for the research and testing of various cooperative scenarios due to their flexible structure and their broad-based sensor concept. A master-slave concept to control the participating machines was developed and tested in simulations as well as in the field using the comRoBS. In addition to approaches to path planning and collision avoidance, which are based on a separation of the planned paths, methods for parallel guidance during the overloading process were considered. The results are promising and can be transferred to real scenarios and machine swarms, especially in relation to the issues of communication and cooperative path planning.

Fig. 3



Relative positioning

Literature

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