A Basic Approach to Implement Guided Tractor Control

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ABSTRACT

Within a continuous development of mobile agricultural machinery the application and further introduction of electronic controls is offering the fare most potential for working processes optimization. The article gives an introduction to tractor and implement controls, especially targeting implement guided tractor control, underlined with two executed examples for this advanced control design. A structured development model and basic knowledge on safe and robust control loop set-ups were developed. Potential conflict scenarios within the multi master control system of driver, tractor, implement and independently pre-planned task control were identified and solved by arbitrational state strategies. The two exemplarily executed demonstration examples utilize different control commands to functions and interfaces of the tractor. One example is an implement guided headland management; the other is a PTO torque guided tractor speed control. Both automation strategies have been pre-simulated and implemented introducing ISO 11783 communication protocol. Results from final field tests are closing the paper.

Keywords: Implement guided tractor control, ISO 11783, ISOBUS, process optimisation

1. INTRODUCTION

The improvement of handling and comfort in general is a prior motivation for the employment of electric and electro-hydraulic systems. In particular the goal of maximum work efficiency along with high precision still remains focus of research and development on mobile machines (Auernhammer, 2002; Renius, 2002).

In order to enhance functional safety and the efficiency of working processes on mobile agricultural machinery today a multiplicity of networked sensors and controllers are already introduced to modern machine systems of tractors, implements and combines. Although self propelled machines are becoming more and more process optimised, the primary focus within tractor implement combinations is on independent supervision and control of single implements or the tractor and its interfaces separately.

An advanced automation approach that focuses the tractor as a process master would need the implement manufacturers to provide a kind of “driver”-software to be integrated into the tractor ECU. The implement ECU then could be reduced to a smart actuator (Hofmann, 1999; Seeger, 2000).

The approach of “implement guided tractor control” shifts the process control to the responsibility of specialized implements, which may use existing and mostly standardised energy interfaces on the tractor process-optimally according to their installed functions and strategies (Martinus, 2005; Freimann, 2004).

The defined ISOBUS communication protocol (ISO, 2002) as a specialized CAN (ISO, 1995) based network protocol for agricultural machinery comes with all the needed definitions to realize such advanced controls. Table 1 shows a rough overview of achievable controls in a closed loop of tractor and implements.

Table 1. Tractor information and external commanded resource access.

Component / system	Control target (tractor resource)	Actual Value	Transmitted target information
Hitches	Rear hitch position	Primary or rear hitch status	Hitch and PTO commands
	Front hitch position	Secondary or front hitch status	
PTO speed	Rear PTO rotational speed	Primary or rear PTO output shaft	
	Front PTO rotational speed	Secondary or front PTO output shaft	
Hydraulic valves	Operation status and oil flow of hydraulic valves	Auxiliary valve (1-15) measured flow Auxiliary valve (1-15) estimated flow	Auxiliary valve (1-15) command
Power beyond	Hydraulic pump flow	Auxiliary valve 0 measured flow Auxiliary valve 0 estimated flow	Auxiliary valve 0 command
Power train	Theoretical velocity	Wheel based speed and distance	Implement remote control command
	True velocity	Ground based speed and distance	
	Momentary valid velocity target	Implement remote control command tractor response	
	Momentary valid velocity saturation	Implement remote control command tractor response	
Navigation	Front steering angle	Implement remote control command tractor response	Implement remote control command
	GPS position data	Navigation system message	-

2. PROCESS CONSIDERATION

Within the conventional automation approach tractor and implements are operated separately. Even new approaches like teach-in functions are based on men machine interfaces residing on the tractor. System optimisation is divided into “tractor control” and individual implement control as shown in figure 1 (left). The co-ordination of tractor and implements remains operator’s task. The function of the ISOBUS is reduced to an advanced communication system.

The right side of figure 1 shows an alternative set-up of the system communication according to the defined possibilities of ISO 11783: The top level system co-ordination can be reduced to a process related minimum of driver intended control targets and start/stop commands. A sensor-actor based control algorithm then may be transferred to specialised implements, while direct operation control of the driver could be reduced to emergency access, process specific super control and exception handling.

This communication structure implies that there is a multiple access also to single tractor interfaces at one time possible. Within the standard specification of ISO 11783 these are the operator, attached implements and additionally the task controller. Modern tractors and the upcoming part 14 of ISO 11783 hold a fourth automatic function accessing the tractor resources. These are the “tractor management” and “teach-in and replay” functions.

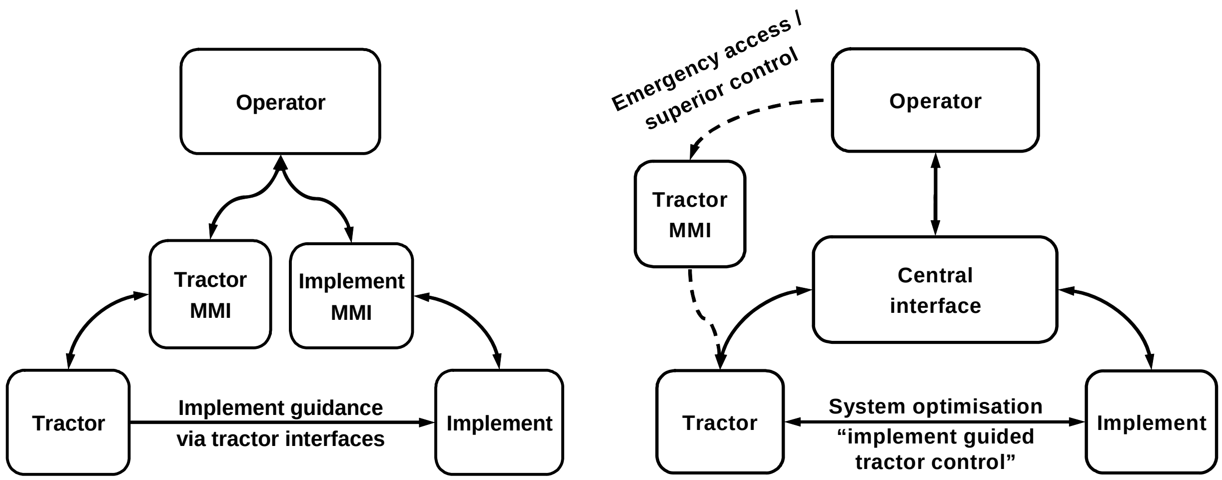

Figure 1. Conventional (left) and advanced (right) communication structure of MMI = Men-Machine-Interface.

To robustly access functional safety and potential conflict scenarios a tailored procedural development model according to the commonly known V-model for software design was applied (fig. 2). The V-model process details more and more into decomposed function requirements and module design. It starts with a system analysis and fits to the software integration at the very bottom. Following the path up to the complete system validation, more and more integrated function models are tested against their prior defined requirements.

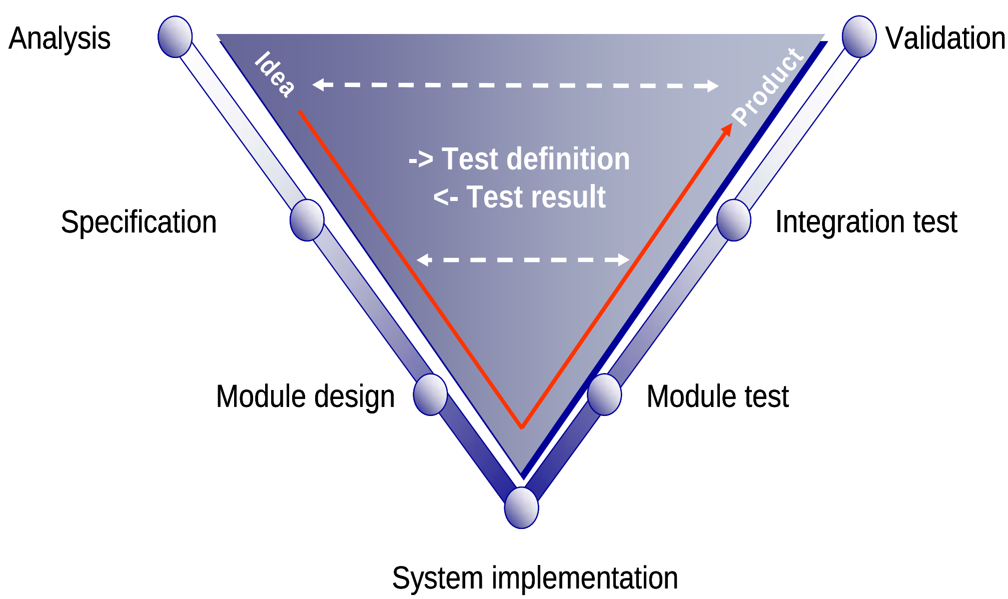

Figure 2. Procedural development mode, V-model.

To allow more than one controller to be active at a time, an access conflict could be solved by a distinct as well as resource and configuration specific priority strategy. Within a centralised approach this state control preferably resides within the tractor ECU. This requires the tractor ECU accessing not only the tractor internal functions and the ISOBUS, but also all necessary operator interfaces.

3. REQUIREMENT ANALYSIS AND DEVELOPMENT TARGET

In order to prove the feasibility of an implement guided tractor control according to ISO 11783 the demonstration project had to cover a set of requirements. First of all suitable automations have to be developed targeting partly simultaneously at tractor interfaces like hydraulic valve or speed and hitch commands. In addition also operator interfaces and tractor or the implement internal controls should be included. Also open control loops for precision farming and site-specific applications may be regarded using the defined ISOBUS task controller.

Figure 3 shows the selected tractor implement combination with impactor, rotary tiller and pneumatic seeder. This combination comes closest to the settled requirements and represents also a very common system set-up within modern grain cultivation.

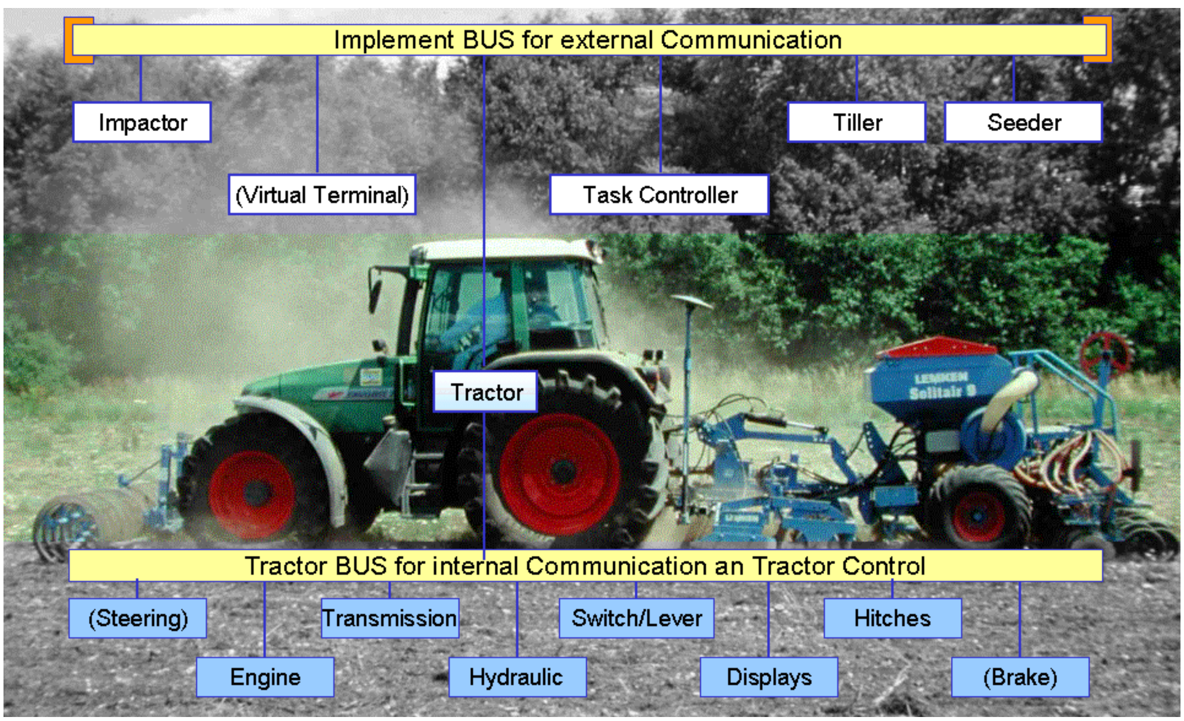

Figure 3. Tractor-implement combination with impactor, rotary tiller and pneumatic seeder.

In variance to a today’s standard set-up the seeder is hitched up to the tiller and not fix mounted. This offers an additional control for a hydraulic valve actuation. To prove the new automation approach the demonstrator combination was subject to two advanced “implement guided tractor controls”.

3.1 Headland Management

The first examined automation was an advanced headland management with a single button engage/disengage control. For operation the driver simply pushes the control button when approaching the headland periphery (fig. 4). The aiming distance from the drivers' viewpoint can be pre-adjusted via the virtual terminal. Alternatively it would also be possible to feed the task controller from navigational GPS information. Once the button is pushed, all implements individually control their tractor interfaces according to the requested engage/disengage operation. Based on pre defined parameters within the tractor co-ordinate system the implement ECUs calculate their driving distance from the tractor speed information. Each implement commands a maximum velocity. The impactor additionally actuates the front hitch. The Tiller commands the rear hitch, the PTO and the hydraulics for the markers. The seeder commands the hydraulics for the additional hitch up and the pneumatic fan power supply.

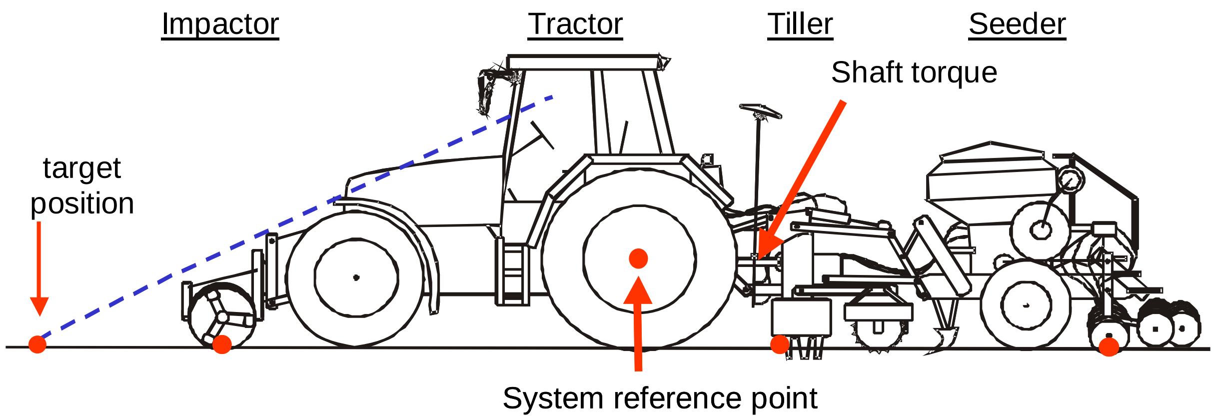

Figure 4. Reference points of the automation example.

3.2 Soil Cultivation

The second examined automatic function was a potential optimisation of the seedbed preparation by target soil treatment. Controlled variable is the tractor velocity guided by a nearly kept constant PTO torque input to the rotary tiller. The idea behind this automation was that for soil preparation quality a site with more compact soil would need more tiller rotations per area than a site with less compact soil. While the PTO speed - due to the tiller design - was kept constant the driving speed is a possible variable. Agricultural proves of possible benefits were not subject to the investigations.

4. AUTOMATION STRATEGY BASED ON ISO 11783

Based on tractor ECU class 3 properties - as defined in ISO 11783 part 9 (Freimann, 1999) - the two automation strategies have been realised according to the signal and protocol specification of ISO 11783 part 7 (implement BUS). The communication structure in figure 5 shows the sequential process communication within two hierarchical levels. On the top level (1, 2, 3, 4) the task controller is in charge to process the overall system application according to the implement working states (engage/transport/park) and the required application rates (e. g. seeds per ha). On a sublevel of the automation (A, B, C) the implements themselves are controlling the tractor interfaces according to the task controllers' commands. Except the turning manoeuvre and the row guidance the driver interfaces during operation can be reduced to:

- Start/Stop initialisation for the headland management (one button)
- Pre setting of the individual desired view point to the headland periphery (distance)
- Pre setting or on-line adjustment of individual chosen limits for driving velocity and PTO torque as potential variables for the soil preparation quality by tilling intensity.

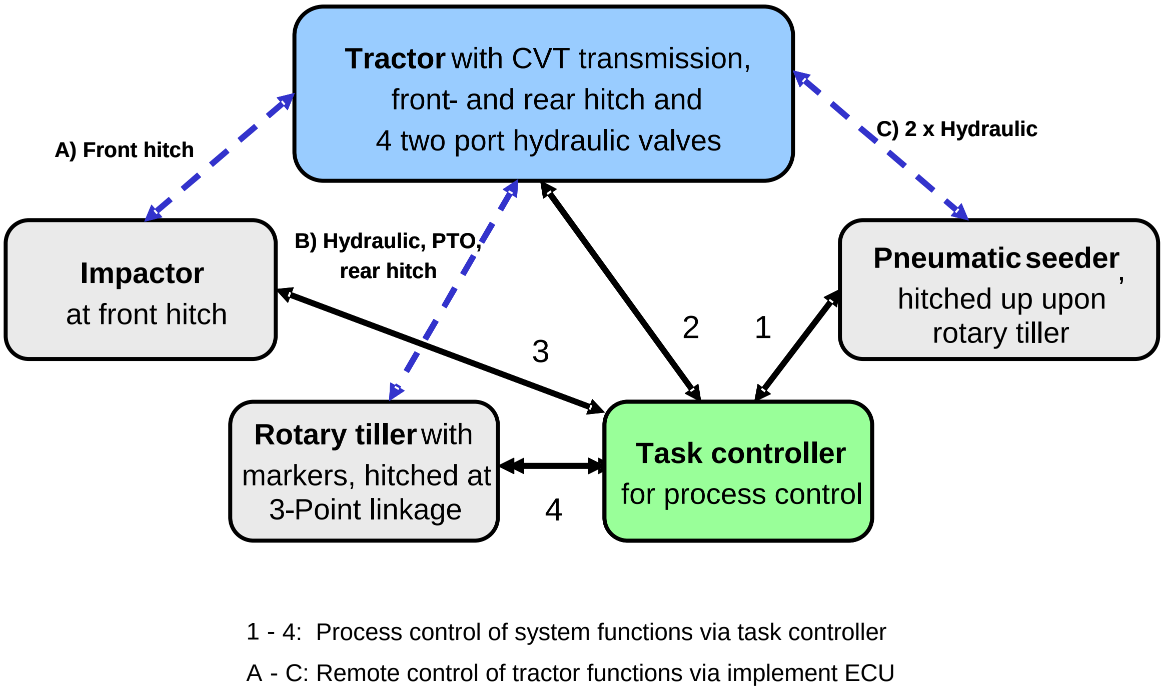

Figure 5. Communication structure on the implement-BUS.

5. MODULE DESIGN AND SYSTEM SIMULATION

The first function decomposition of the tractor implement combination is on system level, assigning an individual macro software component to the tractor and each implement. The next decomposition step is to separate subsystem internal functions (e. g. application rate control of the seeder) from top-level related functions (e. g. velocity control). Along with the software component decomposition the signal interfaces have to be defined. On top-level level this interfaces are defined by ISO 11783.

To achieve a complete system simulation including the ISO defined communication, a real-time co-simulation of Matlab/Simulink for the functional part and CANoe for the communication part was developed (Freimann and Fellmeth, 2001).

5.1 Simulation Set-up

Within Matlab/Simulink a structured model-in-the-loop simulation was developed including modules for each controller software component. The simulative "backbone" of the physical tractor-implement system and the environment was simulated based on energy and force feedback loops (Meys, 2001). CANoe itself is a network design tool including simulation of physical CAN behaviour. Additionally the CANoe "option ISO 11783" comes with a predefined ISO data base and a build in functionality of a virtual terminal and ISOBUS network management. Co-simulation of both tools, Matlab and CANoe, was done via a commonly accessed variable data base. CANoe was set to simulation timing master in order to prove the correct ISO communication. An additional CAN hardware interface connected the simulated CAN-BUS to a physical CAN communication and allowed to validate the Simulation in an early state. Tests were done among the manufacturer groups that participated to the ISO 11783 "plug fests".

5.2 Module Design and Safety

As an example for an "atomic" (least decomposed) function module figure 6 displays the chosen approach to a tractor ECU safety module related to control access to tractor internal resources. Depending on the system status this module proves the necessary states to grant access to tractor internal function to the requesting source. Within the arbitration priority check the driver access always comes first, followed by the tractor ECU as the energy co-ordinating instance. On third priority are the implement ECUs which are responsible for machine control on a sublevel. The last priorities were "external" target values coming from application control or diagnostic and service functions.

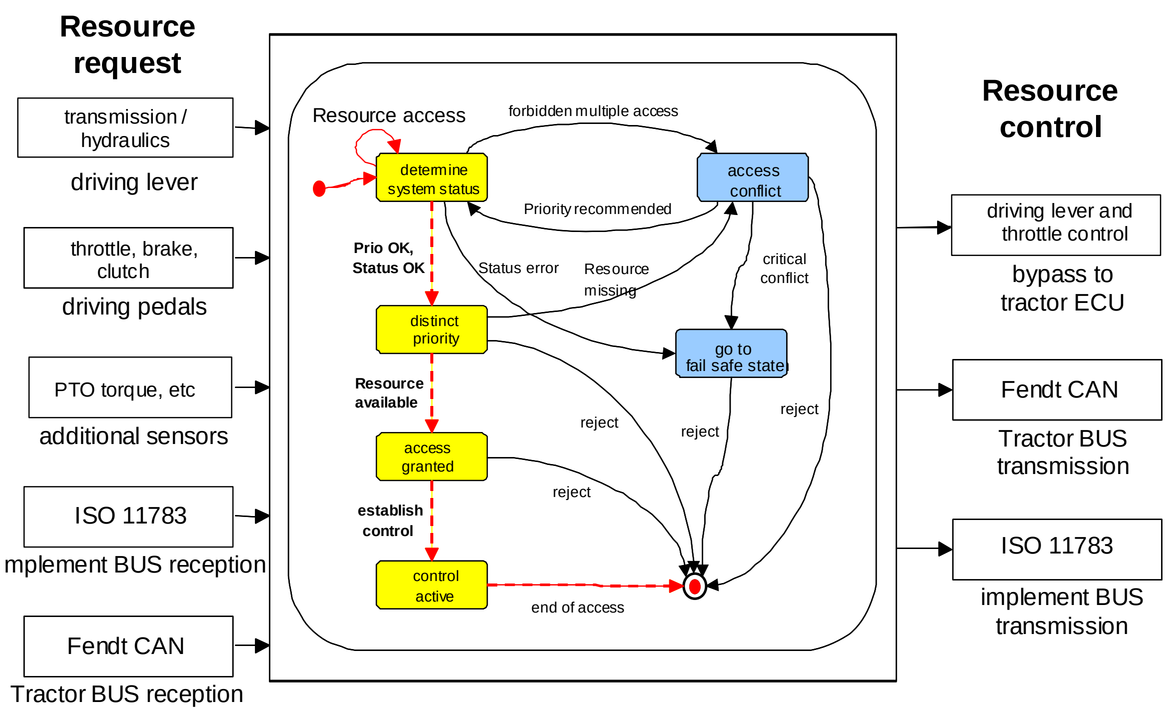

Figure 6. Approach to a tractor ECU safety module.

A closer look to the different tractor resource leads to a basic distinction between multiple and single accessible resources. While single accessible resources like the front or rear hitch have to be dedicated to a single requesting controller on system set-up time, a multiple accessible resources like the driving speed can be managed on run time for example by granting the lowest demanded speed (Martinus and Freimann, 2002).

Within the model-in-the-loop simulation it was possible to verify the chosen strategies without the potential risks of damage during a real field test. A second step of testing had been done by integrating the real tractor into the simulation using a CAN hardware interface to CANoe.

6. FIELD TEST AND VALIDATION

For the verification of the newly designed functions, the Technische Universtität München had offered an uncultivated field that could be prepared as needed. The surface was quite plane and homogenous without reasonable differences in the compactness of the soil. In order to achieve reproducible test conditions for the headland management and to prepare significant changes in soil compaction a reference field was designed within the test field. The preparation had been done by cultivating or compacting the soil transversally to the working direction as shown in figure 7.

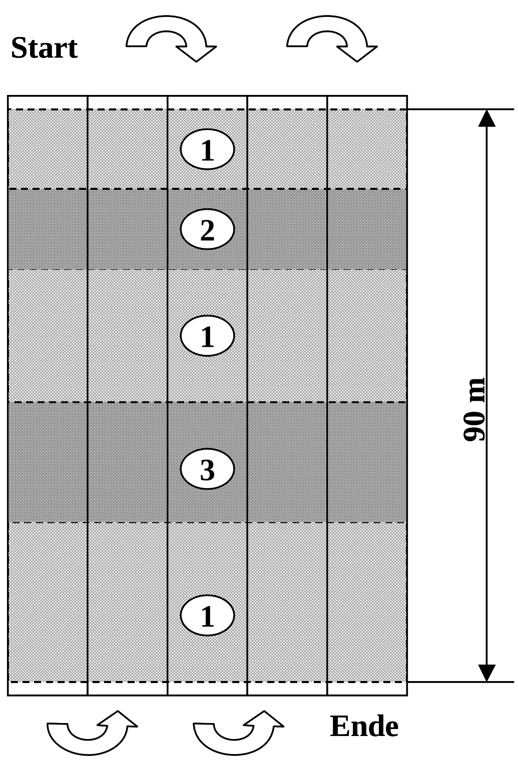

Figure 7. Designed test field.

Examining the PTO torque as a possible control variable for a continuous quality in the seedbed preparation especially the variance of the soil compaction not the absolute value influences the test results. For the control pre-settings the operator only has to set a target torque value, which would equal the desired, working performance - depending on the soil parameters. Setting the target to an expected average value the system would control the velocity accordingly. Setting the target to the maximum scale the system would try to set the velocity as fast as possible until the equalling soil resistances or another speed limit is reached. Individual absolute velocity limits from all connected controllers pretend single system components from overload because the arbitration to tractor velocity is strictly done with a "select low" approach.

A basic dependency between PTO torque and driving speed was proven by preliminary speed variance tests. Also the dependency between working depth and PTO torque was proven as expected. An analysis of the influences of other soil parameters (e. g. water) was not undertaken.

Based on the test results the implement guided velocity control was pre-designed in the simulation set-up. Due to the working forces and the system inertia the best results were achieved by computing big steps to the target speed with even small deviations from the target torque. Big steps within the calculated target velocity are demanding the transmission controller of the tractor to select the maximal acceleration range, thus resulting in an overall sufficient fast response to the actual system velocity.

Figure 8 shows a working trace with an active velocity control guided by the tiller. Under the active control the PTO torque (5) is not constant but still varies around the operator-selected value of 300 Nm. On the other hand the controlled velocity (1) varies very much. The tiller ECU sets target values between 0.75 and 1.5 m/s to the velocity to be processed by the tractor ECU.

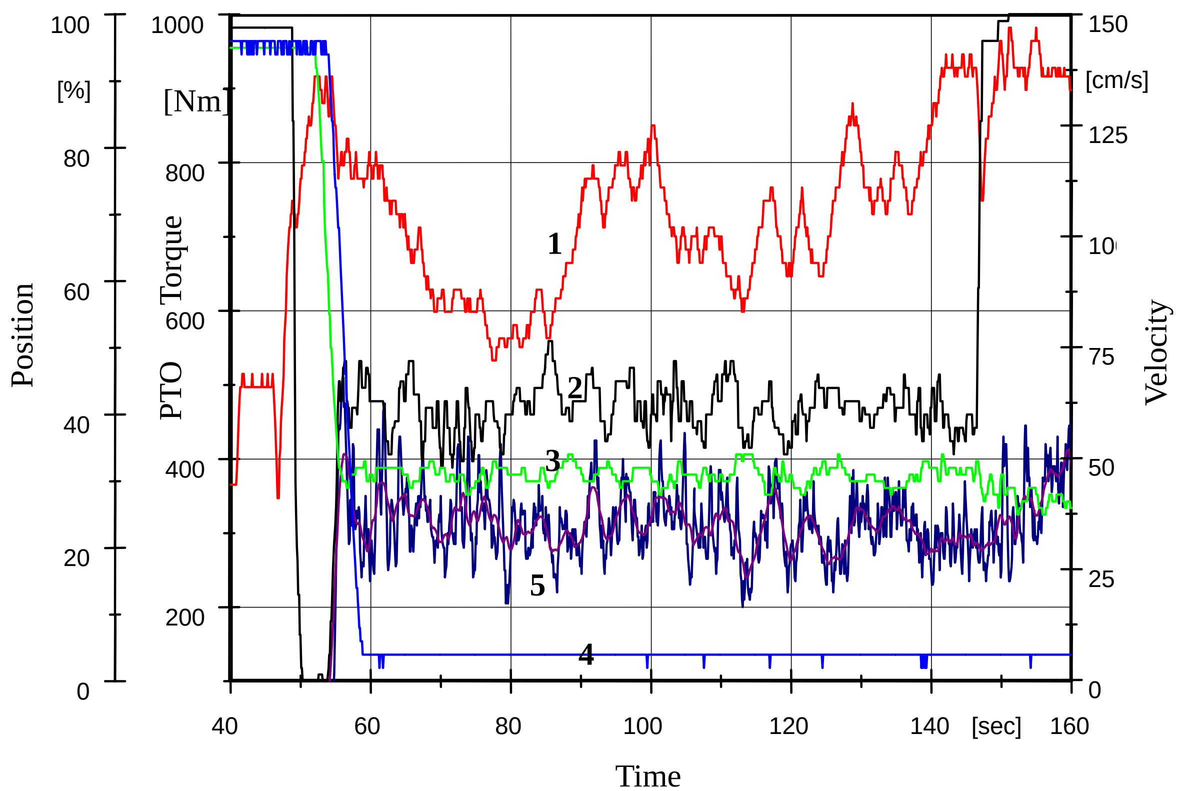

Figure 8: Trace with PTO torque guided tractor velocity: 1 = velocity, 2 = pos front hitch, 3 = pos rear hitch, 4 = pos hitch-up, 5 = PTO torque

Target of an optimised headland management is time saving and operator workload release during the turning manoeuvre. While the system engages all velocity controllers within the tractor implement system are active. The implements feed their designed maximum velocity and their actual requested target value to the tractor ECU. Superior to that are a driver selectable maximum and an eventually active tractor management. The starting point of the implement-individual engage procedure is calculated from the actual velocity. Starting with an average value an integrated continuous self-learning algorithm optimises the engagement timing from activation to activation to better hit the target point. Deviations of the implement mass due to seed consumption or collected dirt on the implements therefore could be as well adjusted as deviations in the oil viscosity.

Figure 9 magnifies a trace to a close up of the real engagement procedure. Started with the "one-button" control the tractor accelerates until the impactor ECU sets a first limit to the target velocity (1). The tractor is decelerated only a short time. This allows the impactor to engage at the correct position. At that point both rear implements are still carried in transport status and the unbalanced weight causes the tractor to pitch backwards. The front hitch (2) therefore drops to the tractor indicating 0% front hitch height. Engaging the rear implements the tractor pitches back to the front again and the impactor is released to float on the ground at about 40 % front hitch position. Since the impactor is engaged, the impactor ECU sets the target velocity to "don't care" and the tractor accelerates again until it is decelerated by the partly parallel engaging tiller and seeder. After the whole combination is engaged, the above described process control of the tiller ECU takes over the velocity control of the tractor.

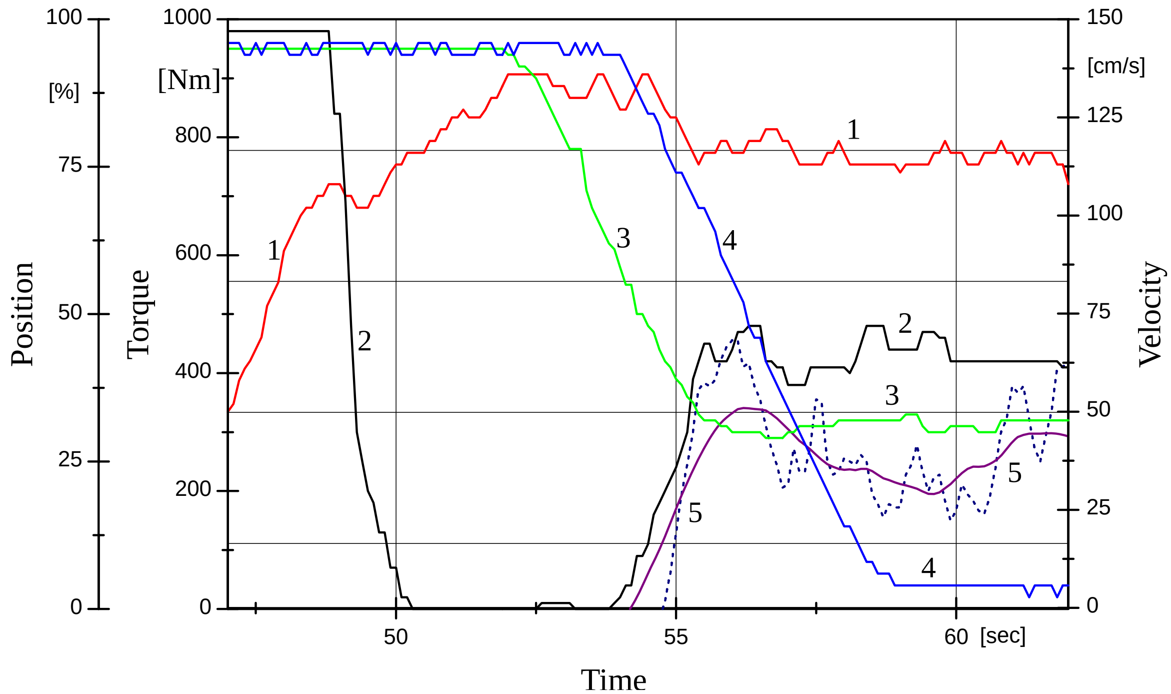

Figure 9: Trace of implement guided tractor velocity during engagement: 1 = velocity, 2 = pos front hitch, 3 = pos rear hitch, 4 = pos hitch-up, 5 = PTO torque

7. CONCLUSION

The applicability of the chosen development process for advanced agricultural field-automations had been approved by realisation and test of two advanced implement guided tractor control functions. Simulated network nodes were used to pre-determine the communication effort and the standard conformity to ISO 11783. The simulation based system and controller layout could be optimised by feed back from the test results.

The functional layout was based on a system simulation and did deliver Simulink files as a detailed software design duty book for each network node. Using the dSPACE MicroAutoBox as a rapid prototyping system for the tractor ECU, the respective Simulink file could be integrated directly into the tractor controller. The implement ECUs of impactor, tiller and seeder were C-coded strict to the duty book. The CAN-BUS simulation has been a substantial support for design and test of the real tractor ECU without the risk of connecting the real implements in the first.

The introduced automation and safety strategy for process automation also leads to a potentially general approach for a self-configuring and secured interoperation of tractors and implements of different make - based on ISO 11783. The suggested automation and communication structure and the arbitration to tractor resources by priority and resource type are allowing a universal approach to resolve access conflicts within an implement guided tractor control. The chosen automation examples provide an interesting outlook to the possible challenges and benefits to come introducing "implement guided tractor control" to the automation of agricultural off road equipment.

8. ACKNOWLEDGEMENTS

The author likes to thank the Deutsche Forschungsgemeinschaft (German Research Foundation) and the companies AGCO-Fendt (tractor), Lemken (implements) and Walterscheid (torque sensing drive shaft coupler) for generously supporting and assisting this research project at the Technische Universität München. Many thanks also to the former colleagues of the standardization working group of ISO TC19/SC23/WG1 and the experts at the VDMA "Fachverband Landtechnik". Very special thanks are going to Prof. Dr.-Ing. Dr. h.c. K.-Th. Renius for supervising the project and to the former colleagues at the institute of agricultural machinery, especially to my workmate Dr.-Ing. Marcus Martinus, who focused on the functional safety in this research project.

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