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Description of the operator's tasks with a tractor-implement combination as a basis for further automation developments in agricultural engineering

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This paper presents a 3-level model describing the work task of an operator performing field work with a tractor-implement combination. Taking the process step "stubble cultivating" as an example, this model is developed in course of a holistic approach of the work task itself. Based on the 3-level model, an outlook how it could be utilized as a basis for the development of advanced technology to further automate a tractor-implement combination is presented.

Keywords
3-level model, automation, tractor-implement combination

Current concept studies show a clear trend leading towards highly or fully automated agricultural machinery. In general, there are two major concepts:

- In the past there have been presented prototypical studies which take up the existing basic concept of a tractor. By equipping the tractor with appropriate advanced sensors, it is further developed into a highly or fully automated solution (Stentz et al. 2002, Foster et al. 2017, Tarasinski et al. 2018).
- Furthermore, several manufacturers are working on field robots and so called "swarm solutions" for autonomous field work (AGCO 2019, Albert 2014). Such systems take advantage of a light and compact design of the single swarm members. Swarm solutions are usually designed for executing a specific application.

Although both approaches follow different concepts, in both cases the human can be supported or even substituted by technology while performing field work with agricultural machinery. Thus, it is essential to develop approaches which translate the expertise and skills of a human into automation technology.

In general, the work task of a human operating an agricultural machinery can be divided into the two subtasks "Driving" and "Monitoring and Controlling the Work Process" (Streitberger et al. 2018, Becker and Geimer 2018). Both subtasks comprise a complex spectrum of tasks, which is further elaborated below.

Certain aspects of the subtask "Driving" have already been covered in commercially available GPS-based steering systems (Deere & Company 2020). Those commercial products can be located at automation level 1 or 2 in the model of Streitberger et al. (2018). Furthermore, the concept studies mentioned above have most often addressed perception problems as part of the subtask "Driving".

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A clear imbalance in favor of the automation of the subtask “Driving” can be found when comparing state of the art in process automation of a tractor-implement combination to state of the art in automation of the subtask “Driving”. In addition, there is a lack of systematics in the description and decomposition of the operator’s work task. This is exemplified at the process step “stubble cultivating”.

State of the art

A systematical approach to defining single levels of automation in agricultural engineering following the automotive standard “SAE J3016” is derived by Streitberger et al. (2018). CASE IH (2018) is presenting a framework to cluster categories of automation and autonomy in agricultural field applications. Few studies have been published so far addressing the automation of the subtask “Monitoring and Controlling the Work Process”. These contributions mainly cover the optimization of specific agricultural processes:

- The contribution of Riegler-Nurscher et al. (2017) describes the optimization of the work result of a rotary harrow by controlling certain parameters of the tractor-implement combination based on a soil surface roughness estimation with a stereo camera.
- The contribution of Becker and Geimer (2018) describes experiments determining the depth of a plough furrow with several sensors, such as a LiDAR and a stereo camera
- The work of Steinhaus et al. (2018) is presenting a method which enables the efficiency evaluation of a single agricultural process based on fuel consumption and job quality. According to Steinhaus et al. (2018) there is a potential to increase energy efficiency on a level of the whole agricultural process chain and on a level of each individual process step. In addition, there are taken measurements to assessing criteria of job quality in stubble cultivation. This mainly aims to show how this method could contribute to meet fuel economy goals. Real-time optimization algorithms have not been presented.

The development of highly or fully automated solutions usually takes observations how the human is solving the corresponding task as a starting point. In literature, there can be found a small amount of contributions which roughly describe the work task of the human doing field work on an abstract level:

- The contribution of Bottoms (1982) describes the tasks of a human doing work with an agricultural machine in a general way. According to Bottoms (1982), vehicle velocity is set with regards to job quality aspects under normal conditions. Furthermore, it is pointed out that job quality is the more important part compared to work rate. This is demonstrated with control loops. In addition, it has been remarked that a fully representation of the work task needs more control loops.
- Automated field work in general has been described by Renius (2019) as a closed loop control with further control loops in a cascade.
- According to Wegkamp (2009) the task “Driving” is seen only as a subtask of the whole work task. For fulfillment of the complete work task the operator needs to be trained with several kind of skills:
  - Driving skills
  - Operating skills
  - Application skills

Training expenditure for acquisition of these skills is increasing in the stated order.

In automotive industry the description of the driving task has been already systematically investigated since the 1980s'. These investigations are currently taken as a basis for further automation efforts. Over the years the developed approach has been further worked out:

- The contribution of Donges (1982) presents a 3-level model which describes the automotive driving task. This is divided into a "Navigation Level", a "Guidance Level" and a "Stabilization Level".
- This model has been further developed by Werling (2017) and adapted for critical situations in traffic. Furthermore, the driving task is regarded as a superimposed optimization problem. From a control engineering perspective this corresponds to a cascade control.

According to the 3-level model of Rasmussen (1983) human performance can be divided into "knowledge-based behavior", "rule-based behavior" and "skill-based behavior". This model is designed for goal-oriented activities. In summary, these three levels can be described as follows (Donges and Naab 1996, Donges 2015):

- "Knowledge-based behavior": In case the human gets blindsided with complex situations which require untrained ways of acting, the human is falling back to the level of "knowledge-based behavior". Such behavior is characterized by going through several alternatives for action based on knowledge acquired or to be acquired. The alternative that is found to be the most appropriate with respect to the actual objective of the activity is selected. Furthermore, the selected alternative can be stored as a rule for the future (Rasmussen 1983, Donges and Naab 1996, Donges 2015).
- "Rule-based behavior": The human often acts based on rules which have been stored in the past. Out of the repertoire of stored rules the human is selecting the most appropriate based on a subjective evaluation (Rasmussen 1983, Donges and Naab 1996, Donges 2015).
- "Skill-based behavior": Such behavior is characterized by reflexive stimulus-response mechanisms. These mechanisms are carried out without conscious control in a steady flow. These skills are the result of training (Rasmussen 1983, Donges and Naab 1996, Donges 2015).

Donges has transferred these types of human behavior to the different subtasks the human is executing while driving a car (Donges and Naab 1996, Donges 2015). From this it can be concluded that a substantial contribution to research and development can be made by deriving a holistic translation of the work task of the machine operator when working in the field with an agricultural machine.

In order to derive a comprehensive description of the work task, it is important to know the operator nowadays is already supported in several ways by automated solutions. Therefore, one must also consider how several subtasks were executed without such supportive technology.

Description of the work task of the operator when working in the field with an agricultural machine

For the following remarks it is necessary to look at the work task of a single field operation with respect to its overall context in agriculture. Therefore, it is important to look further at the level of a single field treatment and at the level of the agricultural process chain described in the contribution of Steinhaus et al. (2018). This leads to the conclusion there is potential for optimizing the whole agricultural process chain as well as optimizing single treatments. Thus, it can be assumed the farmer nowadays is thinking and acting on both levels.

Nowadays the farmer is making the decision to executing a specific agricultural process step at a determined date with respect to the information basis gathered on the overall process chain level. This means while executing a specific field operation the farmer is mainly focused on its optimal execution. This includes optimal efficiency, optimal work rate and optimal agronomic job quality while ensuring maximum safety during the work operation. Only in case of an exceptional situation the farmer will decide to swap an attached implement if the implement itself has not been damaged. The decision to use a specific implement is made by the farmer on the level of the agricultural process chain. This decision is usually derived by the definition of primary targets for the specific treatment.

Description of the subtask “Monitoring and Controlling the Work Process”

A major challenge on the way towards fully automated agricultural machinery is to deliver a solution for such situations the human is dealing with based on gathered expertise and learned skills. The single subtasks a human must carry out while performing field work can be assigned to the stated levels of the publication of Rasmussen (1983). The tasks and processes the human is doing while working with an agricultural machine on the field will be examined in the following section. Considering the course of decision making during the work process the following scenario can be discovered. This applies especially for a skilled and attentive person (Figure 1).

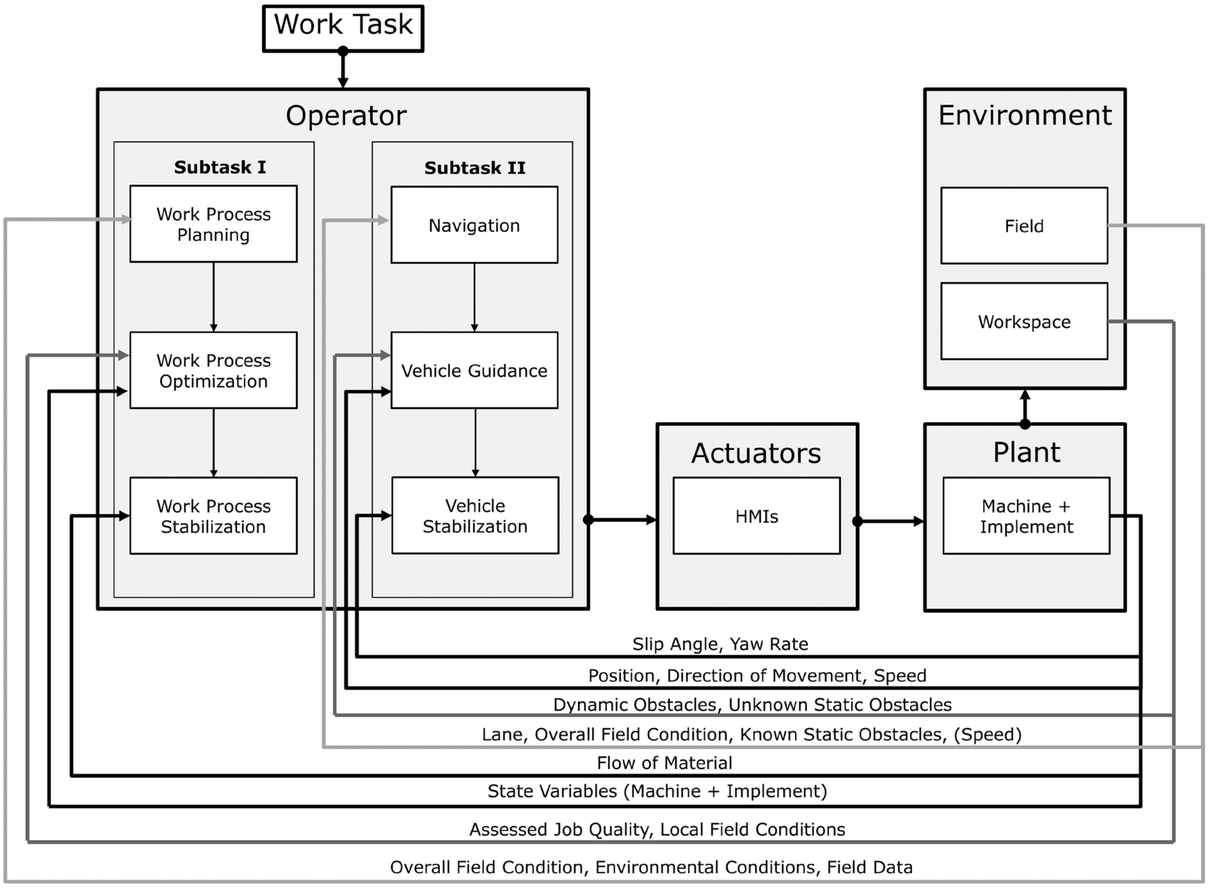

Figure 1: 3-level model describing the work task for the operator of a tractor-implement combination performing field work (Subtask I = Monitoring and Controlling the Work Process, Subtask II =“Driving”)

Work Process Planning Level

In agriculture, the first part of the work task consists in defining targets. Based on such, a plan for the actual treatment is developed. This is comparable to the behavior described by Rasmussen (1983). In agriculture, similarly to the approach that Werling (2017) has presented for the driving task in automotive, one can consider a target of the work task as an optimization criterion.

According to Renius (2019), there are several optimization criteria which need to be considered for the automation of a tractor/ implement combination. In the following, these criteria are considered as universally applicable for any work task with a tractor-implement combination in the field:

- Job Quality
- Performance
- Energy Consumption
- Environmental protection
- Comfort
- Safety
- Economy

At this point it should be noted that economy is strongly correlating with energy consumption, performance and job quality. The economy is the resulting criterion out of the three criteria mentioned before. In context of tillage, environmental protection has a strong correlation with the agronomic work result. Thus, the criteria energy consumption, performance and agronomic Job Quality are investigated further in the following section:

- Agronomic job quality corresponds to process step specific target values which are considered optimal. This target value can vary based on the skills and knowledge of the farmer and regional characteristics. Regional characteristics itself can lead to strongly varying requirements for actual work task.
- Performance can be mathematically expressed as tilled area per hour in case of a tillage treatment. The more general expression is work rate and can be mathematically expressed as hectares per hour (ha/h).
- Energy consumption nowadays generally speaking corresponds to fuel consumption (l/h).

By comparing the above-mentioned optimization criteria, it becomes clear that there does not exist any generally accepted definition for job quality. For performance and energy consumption such definition exists. A separation of energy consumption and performance is favorable because an energy-optimized treatment does not necessarily correspond to an economically optimal result. An economically optimal result also strongly depends on the time of use of manpower and the machine itself. In addition, the target values of the three optimization criteria themselves as well as their weighting below each other can be influenced by other superordinate target from the agricultural process chain.

Usually the work targets get defined before the actual work process starts. Thus, in most cases the planning of the work process is done before the actual job as well. Therefore, planning and execution of the job can be separated in time and space. In this case the operator does a comparison of its expectations and the overall conditions of the field shortly before the start of the job. If expectations and overall field conditions vary, the plan can be adjusted. It is conceivable to separate planning and execution of the work task into two roles. The person planning the work task does not necessarily needs to be the person executing the work task.

Nevertheless, while executing the work task the operator of the tractor-implement combination is occasionally acting on a “Work Process Planning Level” (Figure 1). For instance, in case of changing boundary conditions, such as weather conditions, the operator is adapting the work planning to the new boundary conditions. This means the target values for the three optimization criteria mentioned above get updated. A typical example would be to increasing machine speed, as the work task has to be completed earlier than originally planned due to changing boundary conditions.

State of the art in tillage is nowadays sub-area specific tillage. There exist online or offline approaches. Depending on whether it is an offline or online approach, this is another aspect which must be considered on the “Work Process Planning Level” or the “Work Process Optimization Level”. In general, sub-area specific tillage aims to apply optimal working depth to predefined subareas of the field (Walther 2009). An offline approach usually is based on a database consisting of mapped field data such as soil data (Herbst 2004, Walther 2009). Out of this database an application map can be created. In case of an offline approach there is a separation in time between the date when the data gets collected and the date the tillage is done. Thus, it is not possible to address local soil properties which are time dependent. To cope with this there have been developed online approaches (Herbst 2004, Walther 2009). The resulting application map of an offline approach can be assigned to the “Work Process Planning” level in Figure 1. Furthermore, in case the operator assigns an agronomic target value such as residue coverage or more general speaking a working depth to a subarea of the field based on gathered experience, this also represents a typical action on the “Work Process Planning”. An online approach must be treated as part of the “Work Process Optimization Level”.

Depending on the chosen target values, the operator is applying or adapting dedicated presets on the tractor-implement combination before the operator starts with the actual execution of the field work. Looking further at an example of stubble cultivation, the operator is setting the working depth of the implement. Such actions mark the beginning of the actual execution of the work task.

In summary it can be said that the uppermost level of the subtask “Monitoring and Controlling the Work Process” can be regarded as a “Work Process Planning Level”. Major parameters influencing are the overall field conditions, environmental conditions and mapped field data. As an analogy to Donges’ (1982) and Werling’s (2017) approach, these parameters are treated as state variables.

Work Process Optimization Level

After beginning with the execution of the work task, the operator is focusing on the just created work result. Based on a visual recognition and in some cases a haptic test of the created work result behind the implement, the operator is associating this with its expectation. In case work result and expectation differ, the operator is modifying some settings of machine and implement. For stubble cultivating, such settings could be an adjustment of the hitch or the packer roller position of the implement. Such adjustments can potentially also be made if work has further progressed in reaction to not predictable locally limited field conditions.

The execution of field work with an online soil sensor included into the machine setup is another example of online optimized tillage. Furthermore, the work process settings could be predictively adapted by the operator in response to areas with a highly variable amount of residue in front of the tractor-implement combination or other cases of local field conditions. Such optimizations are based on the perception of the operator for the current status of the work process and, in contrast to actions on the „Work Process Planning Level“, not on pure empirical values. In these cases, the operator is doing an associative allocation of the situation with experiences of the past and choosing a best practice out of its repertoire of stored rules. These situational causal chains are typical for “rule-based behavior” (Rasmussen 1983).

In general, such online optimization is more common in work with active implements due to the narrow working window of passive implements. In addition, a potential for online optimization can also be found in combination of active and passive implements.

The above-mentioned ways to predictively or reactively optimizing the work process are typical examples of real time optimized field work. This characterizes the “Work Process Optimization Level” of the subtask “Monitoring and Controlling the Work Process” (Figure 1). Actions which are running on this level aim to optimize the work process in real time based on the target values which get defined on the “Work Process Planning Level”. The relevant state variables for such real time optimizations are assessed job quality, local field conditions within the current work space and relevant state variables of the tractor-implement combination itself. An example of a relevant tractor state variable is fuel consumption. In stubble cultivation, the reference variables of an optimization are working depth and working speed, as mentioned above. Below, these reference variables will be named as „Process Reference Variables”.

Work Process Stabilization Level

The “Work Process Stabilization Level” represents the third and lowest level of the subtask “Monitoring and Controlling the Work Process” (Figure 1). In contrast to the above-mentioned levels, on this level there is not running any optimization task which is directly related to the defined target values at the Work Process Planning Level”. Moreover, this is the basic task for archiving the process objectives. This level bundles all activities which ensure the specified task gets executed accurately enough by tractor and implement. Furthermore, this level bundles all activities to eliminate or minimize disturbances or failure in the work process as well.

In stubble cultivation for instance, tasks managed on this level are:

- Controlling the “Process Reference Variables” which are defined on the “Work Process Optimization Level”
- Lifting the implement in case of plugging

In analogy to the observations of Donges and Naab (1996), the tasks running on the “Work Process Stabilization Level” cannot clearly be categorized into one category of human behavior of Rasmussen (Rasmussen 1983). Thus, it can be assumed single parts of the stabilization activities are managed with different kinds of human behavior. In case of an implement plugging, it can be assumed the recognition and decision making to identifying a suitable solution for loosening the plug is rule-based behavior. The actual loosening of the plug by rapidly disengaging the implement is skill-based behavior. This applies especially for old tractor models which require the operator to steer the hitch and the implement completely manually.

Based on the explanations provided, the relevant state variable which must be controlled in order to providing a suitable “Work Process Stabilization” is the material flow. This does not only apply to tillage in general but for instance to seeding and fertilizer spreading as well. In tillage, the material flow is composed out of the two “Process Reference Variables” working depth and working speed multiplied by the implement width.

Timeframe of Optimization

In comparison to the approach of Werling (2017) the optimization hoizon is comparable for all three levels mentioned in Figure 1. Overall, this can last round about several hours at “Work Process Planning Level” until some seconds at “Work Process Optimization Level” or even a split second at “Work Process Stabilization Level”.

Description of the subtask “Driving”

The following explanations assume the ride from the farm to the field is not part of the actual work task. Moreover, this is regarded as a necessary preliminary work. In order to describe the driving task with a tractor on public roads one can rely on the approaches of Donges (1982) and Werling (2017). In analogy to the approaches of Donges (1982) and Werling (2017) the subtask “Driving” while executing field work can be divided into three levels as well:

- Navigation
- Vehicle Guidance
- Vehicle Stabilization

A major difference between the approaches of Donges (1982) and Werling (2017) can be found in the area where the driving task is executed. The name “Environment” is suitable for agricultural purposes. Furthermore, it is obvious the work task is executed in a field. In agricultural context the naming “Driving Space” is misleading because all activities are executed following the primary goal to do field work and not simply drive around on the field. Therefore, the correct naming for such area is “Workspace” (Figure 1).

Thus, the highest level of the subtask “Driving” aims to plan a route in the field which is used for navigation. This comprises mainly the selection of an appropriate lane and planning the trajectory to connecting consecutive lanes with a turning maneuver. On the so called “Navigation Level”, known static obstacles as well as the shape of the field must be considered (Figure 1). Sometimes the route is updated because of unexpected traction resistance for example in hillside situations with heavy soil conditions. This marks an exception in the present context as the operator is facing a dynamic obstacle which can potentially influence the whole navigation task.

On the “Vehicle Guidance Level” the preplanned route of the “Navigation Level” gets further refined with respect to dynamic obstacles or unknown static obstacles within the field (Figure 1). Furthermore, it bundles all vehicle safeguarding activities in order to minimize the risk of collisions or other accidents. Thus, most safety aspects during the execution of field work get considered on this level. As mentioned above, soil condition is crucial for traction. In a situation a maneuver is necessary in order to avoid the tractor getting stuck in the field this can also be regarded as part of the “Vehicle Guidance Level”.

According to Werling (2017), the task of the “Vehicle Stabilization Level” is ensuring planned driving maneuvers get implemented with sufficient accuracy (Figure 1). This is done via an appropriate control of lateral and longitudinal vehicle dynamics. This covers safety aspects of the subtask “Driving” as well. Although inappropriate interventions in lateral and longitudinal dynamics also potentially can influence agronomic job quality in an undesirable way, interventions in lateral and longitudinal dynamics predominately belong to the subtask “Driving”.

The subtask “Driving” covers the comfort aspects mentioned by Renius (2019). By applying suitable control of lateral and longitudinal dynamics the operator is controlling the comfort within the given framework by tractor and implement. This is mainly done on the “Vehicle Guidance Level” and the “Vehicle Stabilization Level”. The operator potentially has further options to enhance ride comfort, such as adapting chassis parameter. However, such interventions are not part of the primary driving or work task.

In correspondence to the described levels, the relevant state variable of the feedback path to describe the subtask “Driving” are (Figure 1):

- Navigation: Overall field condition, mapped static obstacles, current lane;
- Vehicle Guidance: Direction of movement, the current vehicle position, vehicle speed and dynamic obstacles or unknown static obstacles within the workspace;
- Vehicle Stabilization: Yaw rate and slip angle;

About the above-mentioned, there are two remarks which should be made:

- Yaw rate is almost irrelevant under regular conditions, but it cannot be ignored in critical situations
- Traction represents the exception of a dynamic obstacle which can potentially influence the navigation.

Interaction of the subtasks and difference to automotive models

In contrast to the automotive approaches of Donges (1982) and Werling (2017), longitudinal control of the tractor under regular conditions mostly belongs to the subtask "Monitoring and Controlling the Work Process". In stubble cultivating, the working speed is an important parameter which must be chosen with respect to the defined target values of the work process. During a turning maneuver or in situations the work process is not executed for some reason, longitudinal control of the tractor does fully belong to the subtask "Driving".

In case of two agricultural machines working simultaneously in a field, the working speed of the second machine is strongly relying on the working speed of the first machine (Oksanen et al. 2019). Therefore, it is important to include speed as a parameter on the "Navigation Level" in order to avoid overlapping trajectories of the single machines (Figure 1). Looking further into lateral dynamics, it turns out driver assistance systems such as "ESP" are not of great importance for field work. Thus, it can be assumed the control of lateral dynamics mainly consists of ensuring the selected lane is kept accurately. Nowadays, there are assistant systems which predictively countermeasure in a slope to keep the implement in exact position within the selected working lane (Reinhards et al. 2015). This represents an exception in agriculture of the "Vehicle Stabilization Level".

The second significant difference to the automotive approaches can be found in the interaction of the operator's subtasks. In analogy to the approaches of Donges (1982) and Werling (2017) a cascade-like behavior within the single subtasks of the operator can be discovered. However, one needs to consider flowing transitions between the single subtasks of the operator. This has been mentioned above with the example of controlling the working speed. In addition, a revised "Work Process Planning" can theoretically result in adapting the navigation route. Furthermore, the human usually can only manage two subtasks simultaneously to a certain extend. According to human nature, the human is multiplexing while executing the single subtasks. This means subtasks are processed in a stack and not simultaneously.

Automation

A full representation of the work task of a tractor-implement combination can be only drawn by providing a feedback path for the state variables of machine, implement and environment (Figure 1). This can be discovered in the automotive publications of Donges (1982) and Werling (2017). This emphasizes the cascade-like structure which has been discovered by Werling (2017) for the automotive driving task.

Commercially available automation solutions such as AutoTrac (Deere & Company 2020) mainly address the subtask "Driving". AutoTrac is assisting the lateral control on all three levels of the subtask. As mentioned above, an optimal lateral control can potentially help leveraging the quality of the agronomic work result in tillage. However, the lateral control is primarily part of the subtask "Driving". Thus, improved job quality can be regarded as a secondary result of an optimally executed driving task.

In the future, the "Tractor Implement Management System" (TIM) (Horstmann 2013) will further contribute to advancing automation of the subtask "Monitoring and Controlling the Work Process". It can potentially automate features of the three levels of the work task "Monitoring and Controlling the Work Process". Horstmann (2013) describes a baler automation and a potato harvester automation with TIM. According to this it can be assumed TIM is mainly automating features of the “Work Process Optimization Level”.

The Model of Figure 1 is a framework for automation in agricultural engineering. For further advancements towards the fully automated tractor-implement combination it is necessary to develop technology which helps to providing reliable information about the current state of following components shown in Figure 1:

- Environment of the agricultural machine
- Tractor and implement themselves

Machine based sensor technology primarily needs to provide necessary information about the work space. This is essential in order to automate both subtasks of the operator. On a “Work Process Optimization Level”, sensors must deliver information about the state of the field before and after the treatment. This is shown in Figure 2.

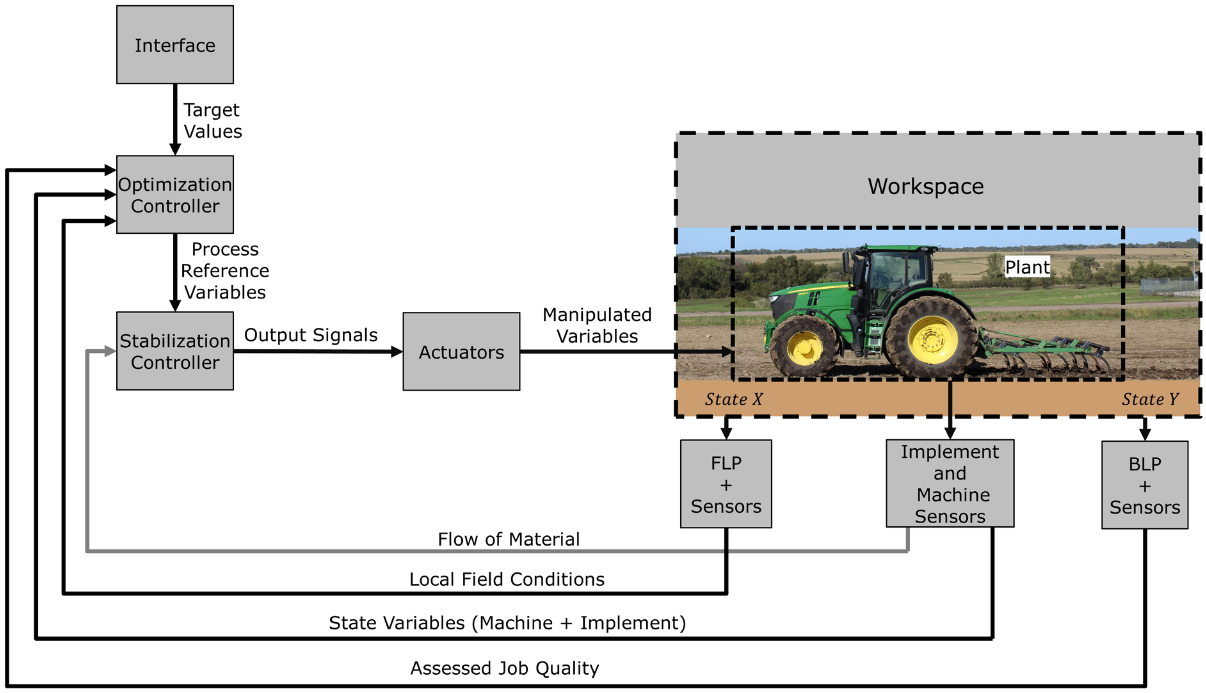

Figure 2: Visualization of the subtask “Monitoring and Controlling the Work Process” translated into an overall technological approach for tillage

Out of Figure 2, on a “Work Process Optimization Level” three possible control loops can be found:

- Optimization based on a “Forward Looking Perception” (FLP) and additional sensor mounted at the front of the tractor (e.g. measuring soil compaction, expected amount of residue in the work space, height/length of the stalks/chopped material)
- Optimization based on the state variables of machine and implement (e.g. fuel consumption)
- Optimization based on a “Backward Looking Perception” (BLP) and additional sensors behind the implement to measure agronomic job quality of the treatment (e.g. residue incorporation/coverage, aggregate size distribution)

Figure 2 distinguishes between “Forward Looking”, “Backward Looking Perception” and further “Sensors”. In general, the term “Perception” covers many types of sensors. However, in vehicle technology the term “Perception” is mainly used to describe environmental sensors such as cameras, LiDAR and radar which are mainly used for obstacle detection. This sensor technology can also be used to sense local field conditions and the agronomic work result. In agricultural engineering, however, the use of process-specific sensors, e.g. soil sensors, is conceivable or state of the art (Geoprospectors GmbH 2020, Bucher 2020). In automation, the above-mentioned control loops always must be combined with subordinate features of the “Work Process Stabilization Level”.

All control loops mentioned are conceivable solutions for field work automation. Some are already within the limits of what is technically feasible. Some aspects of this have already been recorded in patents (CNH Industrial 2017, Deere & Company 2016, Deere & Company 2015). However, a complete automation of the field work aiming to optimize agronomic job quality requires a fusion of all 3 control loops to replicate the human behavior shown in Figure 1.

Conclusions

This paper presents a 3-level-model to describe the behavior of the operator of a tractor-implement combination while executing field work. Furthermore, this model is explained using “stubble cultivating” as an example. The complete work task can be divided into the subtasks “Monitoring and Controlling the Work Process” and “Driving”.

The subtask “Monitoring and Controlling the Work Process” can be further divided into a “Work Process Planning Level”, a “Work Process Optimization Level” and a “Work Process Stabilization Level”. The “Work Process Planning Level” can be understood as a mathematic multi-size optimization problem aiming to provide target values for optimization criteria such as agronomic “Job Quality”, “Performance” and “Energy Efficiency”. These target values get further translated into specific actions on the “Work Process Optimization Level”. The subordinated “Work Process Stabilization Level” is ensuring the predefined actions get executed accurately enough. In addition, “Work Process Stabilization Level” is taking care of disturbances in the work process.

The subtask “Driving” is composed of a “Navigation Level”, a “Vehicle Guidance Level” and a “Vehicle Stabilization Level”. Navigation is mainly covering route planning within the field. Specific maneuvers get planned on the “Vehicle Guidance Level”. In analogy to the approach of Werling (2017), the “Vehicle Stabilization Level” is executing these maneuvers accurately enough. In contrast to automotive approaches, the dominating factor is only the lateral control of the vehicle as longitudinal vehicle control usually is part of the subtask “Monitoring and Controlling the Work Process”. Only in safety-critical situations during field work, maneuvers will be executed to transfer the vehicle into a state of minimal risk. Such maneuvers will be planned on a “Vehicle Guidance Level” and be executed on the “Vehicle Stabilization Level”.

Based on the model it can be found that machine-based sensors need to deliver information about the environment and the tractor-implement combination itself in order to enable highly or fully automated field work. The main efforts regarding environment sensors should focus on developing suitable solutions to monitor the work space of the tractor-implement combination in order to enable automation of both subtasks. In automation of the subtask “Monitoring and Controlling the Work Process”, it is essential to sense the state of the field before and after the treatment to optimize agronomic job quality.

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