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Operator-driven evaluation of mobile machines

To estimate productivity and efficiency of mobile machines due to increasing energy costs and stricter emission regulation, computer based simulation is essential. The necessity and the steps taken for an evaluation method, with which mobile machines with high motion and load alternations can be evaluated regarding productivity and efficiency is presented in this paper. One aspect of the reseach project is the development of an parameter driven operator model. Next to the basic structure of the operator model, the method with which the operator specifc parameters for the path planners und controllers are determined is presented.

Keywords

Efficiency, evaluation, mobile machine, operator model

Abstract

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Next to determining the efficiency and productivity of mobile machines with the help of simulation tools, drive train management systems can be developed and optimised regarding specific requirements. To do this, it is essential to have appropriately detailed models of the power transmitting components and process environment, in which the mobile machine is used.

In this perspective the process describes the task of the mobile machine as well as the environment parameters. Due to high effort to determine these parameters, measured load cycles for example of wheel loaders and fork lifts are used and implemented in so called backward or inverse simulation. The input and output variables, for example speed and torque of the reverse simulation are the output and input variables of the physical drive train system respectively. The simulation procedure has two main drawbacks due to the time based approach.

First, measured load cycles are influenced by the machine (mass, inertia), the environment (traction, bulk material) and the operator. The environment and operator based properties evoke scattering in the measurement run due to their complex context. For this reason Deiters developed a method in [1] to standardise measured load cycles. The control behaviour of the operator can be characterized by the specific task in which the machine is run and the experience level of the operator. The operator experience describes how the operator assesses the machine behaviour and controls the machine in an anticipatory way. An example of this is described by Kunze in [2] where the relationship of the training level of different operators and the equivalent cycle times for material loading with a bucket excavator is analysed.

Second - when component efficiency - which in most cases depends on multiple variables, is considered, the input variables of the simulation model are partly open-loop and closed-loop controlled. Due to this, the correlation of the current (model based) and the stipulated (measurement run based) power is directly dependent of the quality of the implemented controllers. For dynamic processes this is very problematic. This approach is only sensible when the task inhibits dynamic parts which only occur during a relative small proportion of the whole task cycle. Summing up: to simulate mobile machines in task cycles with a high rate of dynamic change it is necessary to consider an adequately detailed illustration of the process environment and the machine operator.

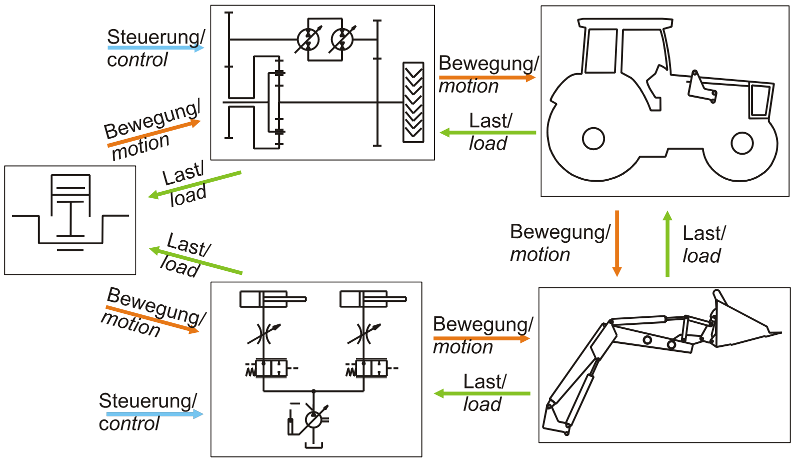
In this project, a method is developed with which a parameter driven operator model can be developed from measured data.

Test machine

A medium power tractor with front-end loader is deployed to capture task cycle data. The traction drive train consists of a hydraulic-mechanical power-split transmission. Typical for tractors, a hydraulic load-sensing system is used for the work drive train (**Figure 1**).

The machine is equipped with multiple sensors, which capture machine-based variables such as speed, pressure, velocity etc. and control or operator-based variables such as drive pedal, drive direction level etc. Currently a simulation model of the tractor with front-end loader is being developed, to verify the operator control model at a progressed stage. The machine model consists of subsystems, which describe the longitudinal dynamics of the tractor chassis and frond-end loader, the tire-

Fig. 1



Maschine model

soil contact, the shovel-material interaction and traction as well as the work drive train. The operator model controls the drive pedal, drive direction and the valves of the work hydraulics, as on the real machine. The steering drive train is neglected due to relative small power consumption. The machine-based variables can be classified track and load based. The tractor chassis velocity, shovel height and angle etc. are track based because the operator monitors these visually. Hydraulic pressures and engine workload etc. are load based and evaluated by the operator indirectly through mechanical vibration and noise.

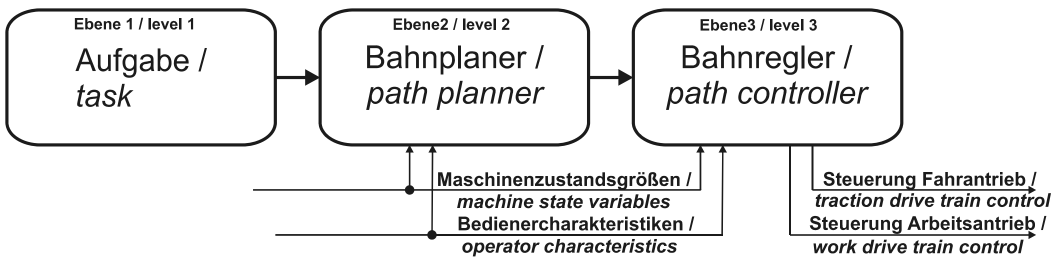
Operator model

In contrast to the inverse simulation approach the load cycle in the direct approach is defined by a task such as loading material from one position to another, which has to be fulfilled. The task contains the process environment parameters as well as the task specific motion pattern of the machine. Regarding the model based description of the operator Filla developed two event based operator models in [3] for the simulation of a wheel loader being run in a loading cycle. The event based approach has the decisive advantage to express the online adaption behaviour of the operator to the machine and the process environment in comparison to a time based approach. In [4] Hughes et al. implement a similar approach for the operator controlling a bucket excavator to analyse the performance of the operator and the interaction between the operator and the machine. The machines used in [3] and [4] have in common that they are generally controlled by professional operators due to their specific operation purpose. In this context, the operator executes the specific task optimally regarding productivity and efficiency of the machine.

In comparison to the aforementioned machines, in this project a mobile machine was selected which inhibits multiple application profiles: in this case an agricultural tractor. These machines are utilised for a variety of agricultural purposes, such as loading of material, soil tillage, transportation etc. Consequently, these machines are controlled by different operators regarding the control behaviour. Generally, the operators can be characterized as professional and all-rounder. Therefore, when simulating agricultural tractors, both operator types have to be considered.

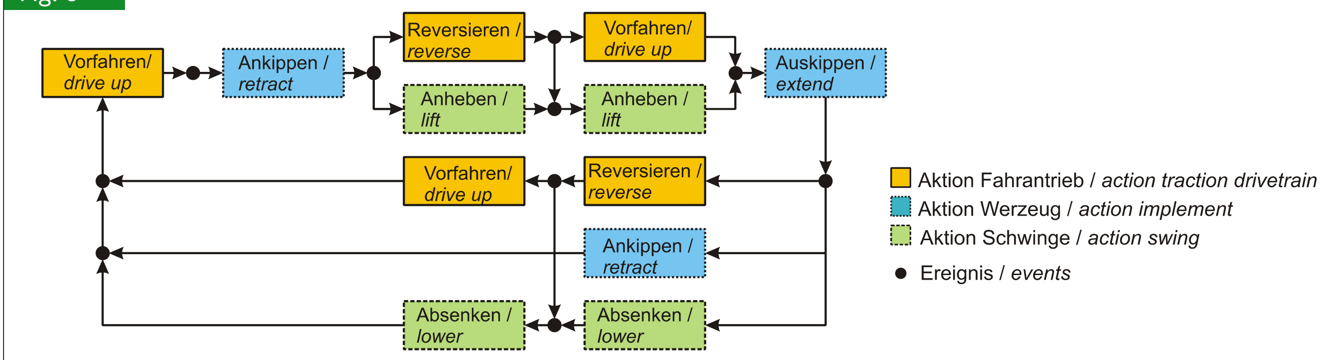
The operator model itself consists of three levels (**Figure 2**). The level "task" defines the working task, which is to be fulfilled. It contains parameters which describe the process environment (e. g. position and properties of bulk material). The level path planner (**Figure 3**) contains motion actions of the machine which the operator has to evoke in order to fulfil the task. The actions are task specific and independent of the operator. The events are split-up into two types: those triggering actions and those who are incorporated into the reactive

Fig. 2



Operator model structure

Fig. 3



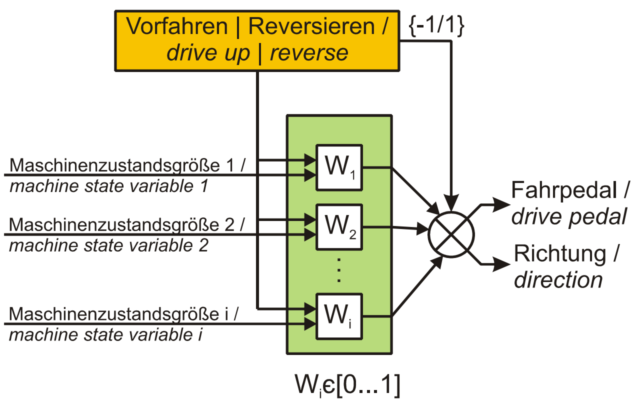
Path planner "loading cycle"

control behaviour of the operator. The type and amount of utilised events is operator dependent. The events are defined by the machine state variables and the operator characteristics. The operator characteristics define when and how actions are accomplished.

The weighting functions W_i of the path controller (**Figure** 4) define the operator cognition and decision-making behaviour specific to the equivalent machine state variable. These functions are determined are determined by analysing recorded measurements run containing the machine state and operator control signals. In the first step the signals are conditioned, e.g. filtered and correlated. The step is essential due to the fact that the signals are captured in different manners (e.g. analog and CAN). In the next step the signals are segmented according to the number of run working cycles. With the help of signal processing methods the signal attributes are determined. Based on the feedback of human operators, appropriate signal analysis methods are selected to determine the action-specific events and the weighting functions respectively. For example, when driving into the bulk material heap results have shown that one operator focuses on the engine workload, whereas another operator takes the relative distance to the bulk material heap in addition to the engine workload into account. Another example for the drive-up task can be found in [5] where the control is velocity based on the one hand and on the other hand a combination of velocity and track.

In **Figure 5** the different control strategies of one operator for the traction drive train in the drive-up phases in the loading cycle is depicted. The data was derived from measurement runs with a professional operator. The data point concentration provides information about the time progression due to the fixed sampling rate. The machine state variable "relative distance" is the distance to the next destination from the operator's point of view. The difference of the curve runs can clearly be observed. The influence can be divided into two parts. The first part inhibits the needed control strategies for the current phase of working cycle, whereas the second part focuses on the following phases "load material" and "deposit material" respectively. The resulting control strategies (force, slip, track etc.) for the phases differ depending on the operator and machine architecture.

Fig. 4



Path controller "traction drive train"

Conclusion

The presented approach provides the fundamentals for evaluating mobile machines, which on the one hand are used in working tasks which evoke dynamic interaction between the operator, the machine and the process environment and on the other hand are controlled by different operator types. Furthermore this approach renders possible the development of an operator specific control model from real measurement data.

Literatur

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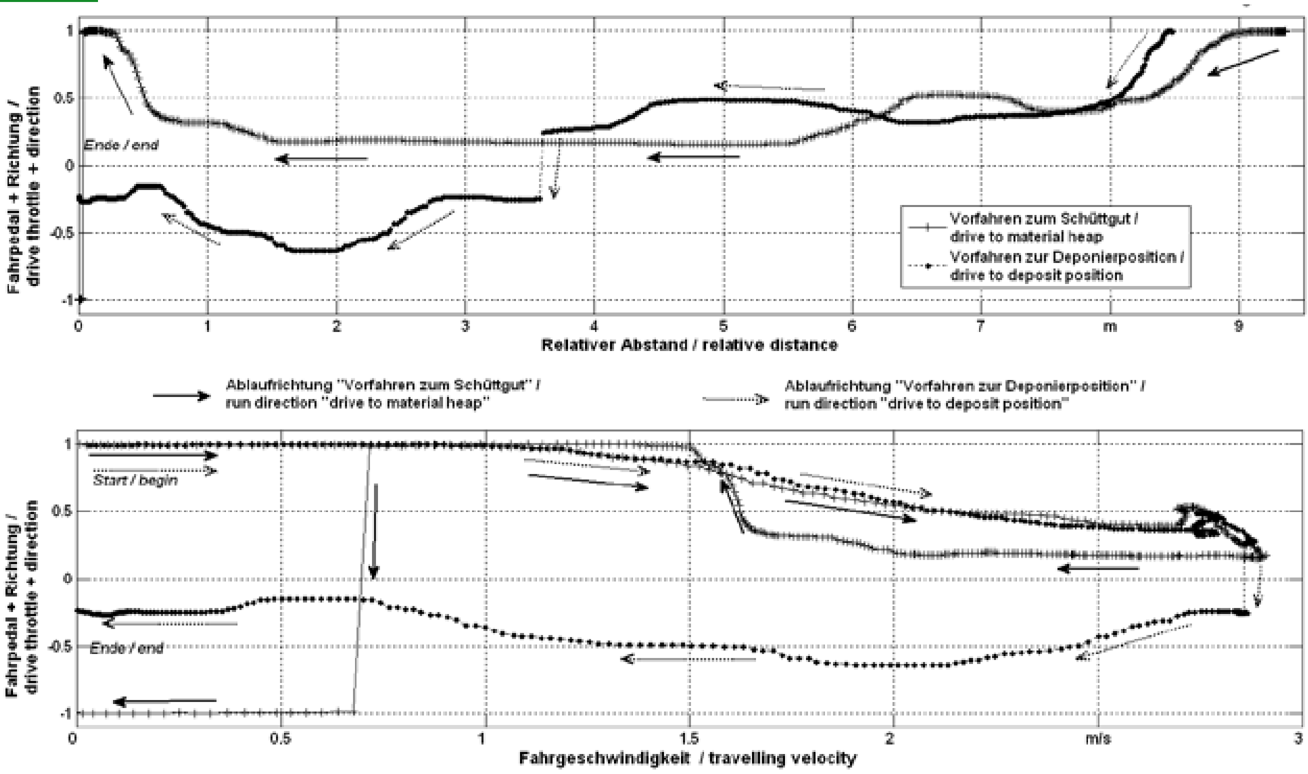
Fig. 5



Drive throttle and direction over relative distance (top) and travelling velocity (bottom) for the drive-up operations in the y-cycle

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