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Application of Assistance Functions in Mobile Hydraulics with the Help of Integrated Position and Velocity Sensors

Since the introduction of electronically actuated valves, the demand for application-oriented machine functions in the field of agricultural and construction machinery has grown continuously. As a result of this, automating mobile hydraulic systems has become more relevant. To present some automation possibilities, within the framework of a project, the hydraulic lifting cylinders of a frontloader were equipped with position and velocity sensors. In this context the closed-loop velocity control, the end position dampening and flexible workspace zoning are being elaborated on and presented, using a tractor with a mounted front-end loader as an example.

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Keywords

Mobile hydraulics, automation, assistance systems

Literature

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[1] • *Heimann, B., W. Gerth und K. Popp*: Mechatronik, Komponenten – Methoden – Beispiele. Fachbuchverlag Leipzig im Carl Hanser Verlag, 2001

Currently implements of mobile machines i.e. front-end loaders are controlled by the operator with the help of an input peripheral such as a joystick. On the one hand the motion behaviour of the front-end loader is dependent of the control input of the operator, on the other hand of the parameters such as temperature of the hydraulic oil, load pressure and pushing/pulling loads.

Closed-loop velocity control

Due to the variation of the mentioned parameters, the operator continuously has to adjust the input signal, to achieve defined motions of the front-end loader. Additionally, the line of sight of the operator is orthogonal to the rotational axes of the implement which results in the operator having great difficulty to estimate the relative position and velocity of the implement. As a result, a software based closed-loop velocity controller for the actuators of the front-end loader has been developed and implemented. The benefit of a closed-loop control in comparison to an open-loop control in this case is the compensation of the velocity deviations of the actuators, which can be up to 20 %. The velocity deviations don't play any role when controlling a single axis. But as soon as synchronised motion sequences of several consecutive connected axes (i.e. swing axis and implement axis of the front-end loader) have to take place, the velocity deviations of the single axes sum up to an overall error hence the predefined motions sequences cannot be achieved.

End position damping

Cylinder dampers have the task to prevent the "slam" effect when the cylinder piston and cylinder housing clash thus reducing the strain of the bearings and increasing the lifespan of the components. Because the impact momentum, which arises from the clash between the cylinder parts, is carried over to the machine operator and evokes physical strain the cylinder dampers increase the time span of well-being of the operator.

Currently most cylinder dampers are either mechanical or hydraulic. Basically they fulfil the above mentioned requirements. It has to be kept in mind that a certain degree of effort has to be taken into account when implementing the mechanical and hydraulic components of the mentioned dampers. The advantage of hydraulic compared to mechanical end position damping is that the damping ratio can be adjusted with the help of a throttle valve. This property allows the adjustment of the damping action depending on the work process, i.e. to set the damping ratio high to knock-off residue of goods in the shovel of the front-end loader such as wet sand at the end of a loading process. The damping ratio of the dampers cannot be adjusted continuously because the operator has to leave the driver cab to do this. Due to the above mentioned reasons a software based end position damping function has been developed and implemented with the help of the existing position and velocity sensors as well as the electrically actuated valves.

The developed end position damping is a function of the position and velocity of the cylinder piston and the damping ratio. The stationary valve of the function is predefined by the residue notch of the valve. A minimal residue notch is crucial for the end position damping because only with the help of this is the cylinder piston able top reach the end positions of the cylinder housing. The software based end position damping has definite advantages compared to the mechanical and hydraulic end position dampers. Firstly, the damping ratio can be continuously adjusted according to the work process via the operator panel. Secondly the cylinder piston is accelerated without delay when leaving the end positions, compared to the mechanical or hydraulic end position dampers where this is not always possible. Finally, the costs for the implementation of the software based end position damping are lower due to the already existing components such as the sensors and valves.

Workspace zoning

Loaders, excavators and similar mobile machines are often deployed in the areas where the operator continuously has to keep an eye on the movements of the machine relative to its surroundings to avoid collisions. An example is the deployment of mobile excavators in the field of railway track construction. During operation of the excavator the operator has to watch out that the shaft, helve of the excavator etc. do not contact the current-carrying catenaries which can result in a hazardous situation for the operator, the machine and the surrounding personnel. This additional strain for the operator results in increasing mental and physical fatigue with a higher possibility of an accident during the period of operation due to declining concentration. For this reason, a flexible workspace zoning for a front-end loader has been developed and implemented. In the following, a short insight of the approach and the implemented methods will be presented and discussed.

The aim of the workspace zoning is to allow a flexible limitation of the displacement of the implement of the front-end loader in horizontal and vertical direction. The front-end loader can be described as a multi-body system [1] (*Fig. 1*). By defining the implement, in this case a shovel as a virtual rectangle with the corner points $P_1, \ldots, P_4$ the geometry of the implement is taken into account. The dimensions of the virtual rectangle can be adjusted accordingly to accommodate for numerous implement dimensions. In the next step a coordinate system is introduced. With the help of direct kinematics, the coordinates of the corner points P_N are calculated relative to the vehicle base coordinate X_0/Y_0. With this step the operator is able to observe and control the horizontal and vertical distance of the implement relative to the vehicle base coordinate system with the help of a visual display on which the coordinates of the corner points $P_1, \ldots, P_4$ are depicted. With the help of inverse kinematics, the movements of the actuators of the front-end loader are controlled. In the following, an example of the actual workspace limitation procedure will be presented. In case the workspace of the implement should be limited in vertical direction, the operator drives to front-end loader to the actual vertical limit point. In following step, the current value of the x-coordinate (horizontal limitation) or y-coordinate (vertical limitation) of the implement is stored in the database of the workspace limitation function with the help of input device (i.e. two-axis joystick with multiple function buttons). Next, the workspace limitation function is activated. As soon as the operator drives the implement towards the set vertical limit, the workspace limitation function adjusts the reference velocity signals, which are set by the operator, of the cylinder velocity controllers in such a way that the implement will not over-run the set vertical limit. The workspace limitation automatically deactivates when the implement is driven away from the set limit.

Conclusion and outlook

With the implementation of integrated position and velocity sensors, three assistance functions were presented and discussed with which the operator of mobile machines can be relieved during operation.

The presented closed-loop velocity control increases the stationary accuracy of the cylinder piston velocity which mainly depends on the parameters oil temperature, load pressure etc. Resulting from this measure, automated motion sequences for repeating working cycles such as overloading of agricultural goods can be established successfully.

The assistance functions end position damping and flexible workspace zoning contribute to operator comfort. The end position damping additionally increases the life cycle of the components such as bearings. The workspace zoning relieves the operator in such a manner that the operator does not have to keep an eye on the position of the implement relative to surrounding objects with respect to collision avoidance. Due to the software based implementation, the assistance functions can be easily activated or deactivated. Additionally the damping ratio of the end position damping of the reference points of the workspace zoning can adapted to operation conditions. A further benefit is the portability of the assistance functions to similar mobile hydraulic systems provided that appropriate position and velocity sensors are implemented. A further enhancement of the workspace zoning can be achieved by making use of a RTK positioning system with which the relative movements of the mobile machine can acquired to increase the deployment area.

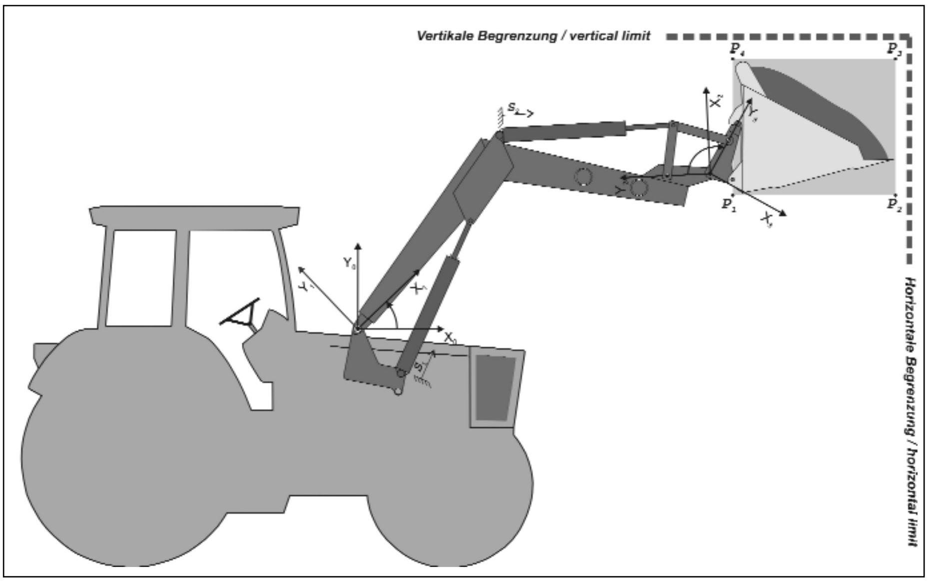

Fig. 1: Approach to flexible workspace zoning