Optimisation of Combine Harvesters using Model-based Control

The world population is expected to grow by over one third between 2009 and 2050 according to the Food and Agriculture Organization of the United Nations. The arable areas are expected to decrease in the developed countries requiring an increase in yield on the available land meanwhile it gets increasingly harder to find qualified operators for combine harvesters.

The performance of the combine harvester is affected by a number of uncontrollable biological variables comprising both temporal and spatial field variations. The threshing, separation and cleaning processes can be optimised by adjusting a number of actuators, however this is not straightforward as the material flows are tightly coupled and the optimisation parameters are even conflicting. Integration of a closed-loop control system is highly challenging as most state of the art process sensors only offer a relative reading of the actual material flows in the combine.

The aim of the project is to design a closed-loop control system than can optimise the performance of the threshing, separation and cleaning processes in a combine harvester. Model development will be required to analyse, optimise and obtain transparency to the system states. The methods acknowledge that a high degree of model accuracy is not achievable as well as the complexity of observer and controller design is kept at a minimum.

Material flow models are generated for the threshing, separation and cleaning systems using acquired material samples from laboratory test stands and field test experiments. Material samples and sensor data are used to generate a virtual combine, which is utilised for initial testing of all controllers, greatly reducing the scarce field test time required for test and verification.

The material flow analysis revealed that the rotor speed had a dominating effect on both separation grain losses as well as grain damage compared to the concave clearance, hence sole control of the rotor speed in the threshing and separation system is chosen.

A Luenberger observer was designed to estimate grain damage from a grain quality sensor, which has a long settling time compared to impact loss sensors. This facilitate a fast response to changes in the separation grain loss in varying conditions.

A closed-loop rotor speed controller was designed to balance rotor separation loss and grain damage using the grain damage observer. The controller was verified by means of simulation as well as during field test experiments.

The material flow analysis for the cleaning system showed degradation of cleaning performance is dominated by the MOG load and inclination angles as well as the effect from the fan speed and sieve actuators to material flows were tightly coupled, similar to the results from previous literature.

It was shown that the fluidised phase characterising low grain losses could be identified using the tailings grain and MOG throughputs. The upper sieve primarily affected cleaning losses and tailings MOG throughput, and the lower sieve the cleanliness of the clean grain throughput and tailings grain throughput, hence these should be controlled using a distributed control scheme for optimisation, where each individual controller primarily will consider two balance parameters.

An estimate of the tailings MOG throughput and tailings grain composition was obtained with reasonable good accuracy using sensor fusion of the tailings grain sensor and the non-linear tailings volume sensor. An on-line estimate of the tailings grain composition set-point characterising the fluidised phase was obtained, which facilitates a novel closed-loop fan speed control design. The fan speed controller was validated using a virtual combine, the cleaning system laboratory environment and during full scale field test. Implementation and verification of upper and lower sieve controllers is not addressed.

The average harvest grain loss in the industrialised countries is 4% corresponding to the total cereal consumption of Germany. Hence reducing the grain loss by a fraction results in millions of tonnes of food as well as it can be the key to maintain a profitable business for the farmer, which is characterised by high revenues and small profit margins.

The contributions of this project enables integration of a control system for rotor speed, fan speed and sieve openings on the AGCO IDEAL series of combine harvesters. The developed controllers are planned to be included in the automation system and will be commercially available in 2019.

The dissertation is a summary of Ph.D. project and the methods developed during the project period. The results are disseminated in four conference articles, two submitted journal articles and one patent application.

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