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Agricultural Field Machinery for the future – from an Engineering Perspective

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Abstract: When analyzing agricultural field machinery from an engineering perspective, it appears that the technical development has progressed in a different pattern compared to what is seen in other industrial mechanical or tooling systems. As in other fields, the technical development of agricultural field machinery has brought new technical and engineering elements into use. Especially for tractors and combine harvesters, where modern mechanical and control engineering solutions are implemented. Developing work on implements has more concerned on monitors, sensors and actuators for the classical adjustment elements. It is special for agricultural field machinery, that the overall design and the tooling principles have changed very little even since the time of horse driven units and during the following up-scaling of tractor and implement size, which has continuously taken place until now, where the power of an tractor is more than 10 times bigger, than for the first tractors.

When analyzing the design of industrial mechanical or tooling systems, the technological and engineering based development has in many cases been accompanied by change of working principles, operation interactions and of the overall design and layout. The assumption is that the development of agricultural field machinery is in a stage where further up-scaling is not the best solution due to optimization of the overall production economy. Instead it is expected probable, that the next design step will involve a radical redesign of the whole systems for the different types of implements. A logical approach is development of compact integrated tooling systems, where propulsion and tooling systems will be integrated in harmonic systems and the design will be dedicated to specific operations. The sizing then, will be balanced due to a new set of conditions.

Key words: field machinery; autonomous systems; integrated systems; agricultural tooling systems; agricultural implements; engineering development; control systems; sensors; actuators.

Introduction

Historically field machinery has always been a subject to development. When visiting agricultural museums you experience, that the old local blacksmiths were very innovative in making implements dedicated to take care of local crops and soil conditions. Since the mid 20th century implements have been improved from being horse driven to being tractor mounted. Since the introduction of tractors in agriculture growing size and capacity has been an ongoing key point of development till now. Over the time, tractors and implements have been more advanced by introduction of sensors and digital display of settings. Furthermore, control of central parameters has been introduced. From an engineering point of view tractors and combine harvesters are more advanced than different implements. For outsiders, a tractor today looks like an up-scaling of the old versions. When looking more closely, you realize that the tractor of today is a result of considerable development due to the overall performance (Renius, 1994) (Kutzbach, 2000). The different elements are optimized by introduction of most recent components and engineering technology. This involves: the hydraulic lift system, drive, gearing, combustion engine. All elements are controlled by modern technology. Moreover, the elements are coupled in an overall control and information system such, that e.g. the engine and gearing can be controlled based on input from the lift, slip etc. The system is open to involve communication with the mounted implement. This is, however, not yet developed to the same level as the tractor's internal system.

Site specific farming has been an area of high interest during the last two decades (CAHN, 1994) (Zhang, 2000). Most focus has been on fertilizing and plant care. Commercial systems are available, which allow a varying dosing over the area. The core topic here is to increase information about needs for optimal care. The driving technology for site specific farming was the availability of satellite based navigation (GPS). This is now available as commercial equipment on new tractors. The accuracy is of a quality that allows the GPS system to control, the guiding of the tractor in the field. In relation to site specific farming and weed control many research groups work on development of autonomic units (Slaughter et al., 2008).

From an engineering point of view, many unused potentials exist in developing agricultural machinery that a major change during the coming decades is likely. Looking at different agricultural implements as the harrow, the plough and the sowing machine, the basic working principle is the same as for the old blacksmith versions. Compared to different industrial products or production systems, the development has in principal been, that manual tools in a first step have been mechanized. Afterwards, the working principle and the design in many cases changed form from a big and clumsy look to a compact, elegant and much more reliable design. This is obtained by utilizing the potentials of modern engineering design and industrial production systems.

Based on this, you might expect that agricultural machinery is facing a development, where the powering unit and the implements will grow together in integrated units, it will be possible to redesign the tooling units and systems based on big knowledge and understanding of the needs in a modern agricultural system with the restrictions in force for environmental impact and future growing fertility of the soil.

Materials and methods

A first important step in the analysis of the direction for future development of agricultural field machinery is to analyze the controlling design driver. Reduction of production costs is classically the central design driver in modern industrial production systems. In general, this is also the case in agricultural production systems. Although, strict conditions on minimizing the harming environmental effect here exist. These primarily concern the need for pesticides, nitrogen leaching, and their negative effects on soil fertility. An example of an operation, which involves the development both directly and environmentally, is the seed bed preparation and seeding. This influences the germination and the crop quality as the main objective, but it also affects the nitrogen leaching and weed intensity (Hansen & Djurhuus, 1997; Cardina et al., 2002).

The pricing of the crop yield is coupled to the production system. Pricing is not only controlled by the physical quality of the food or feed value of the crops. The prizing is also influenced by the public acceptance of the production systems. Here, the environmental impact plays a central role. In countries where agricultural production is allocated subsidies and taxation this is all leveled by the environmental impact due to the production system.

Optimization of agricultural tooling systems is a difficult topic due to the complexity described above. One approach could be to use a value chain model to include all parameters and effects in a common yield value measurement.

During the last two decades much research has been carried out within developing and analyzing GPS based guidance systems. Now, these systems are commercially available from leading tractor brands. In normal operations, the driver operates the vehicle manually during the turning operation in the headland, but in the field the auto guidance takes over. At present, the technology is available to take over the full guidance of the vehicle. This implies not only a release of the drivers work. It also opens a big potential for redesigning the tractor. Due to this, the task for the driver now changes from controlling the driving to taking care of the overall operation performance. Traditionally, the tractor is designed to ensure that the driver has the best conditions for guiding the vehicle and for controlling the implement. If the ultimate use of the auto guidance system is implemented, the tractor can be redesigned to be dedicated to the operation. In fact, this removes many design limitations and opens for an engineering based redesign, where the implement is redesigned such that it meets the tooling demands much more effectively and the mechanical design gets simpler, more dedicated, and compact.

Development during recent years shows a tendency to more self-propelled units as described by (Kutzbach, 2000). Examples on this development are seen for sprayers, slurry tankers etc. The introduction of auto guiding systems will accelerate this development. The hypothesis is, that in the future, we will see integrated self-propelled tooling systems, which are totally redesigned.

An example could be a soil tillage implement, where the propulsion system and tooling units will be integrated in a united compact and harmonic unit. With such a system, it will be possible to dedicate the soil interaction to fit the wanted effect. Also, the soil compression from the moving implement can be designed such, that it is aligned with the overall operation (Green et al., 2011). In such a system all operating units will be controlled according to an overall optimization strategy. In classical agricultural tool design, the goal is to obtain a design, which can operate in a robust manner under different conditions. Here, the tool design has to be able to change performance due to interaction with a control and actuator system. The limiting element in the design will be to provide reliable information about the need for intensity in the tooling operation. This can be achieved by online sensors or by mapped historical data involving soil conditions growing characteristics from previous years etc.

Substantial impact will be obtained from having a dedicated implement which performs the tillage intensity needed and which adjust the soil compaction to the minimal acceptable. With such a system, the nitrogen mineralization and potential leakage will be reduced to a minimum, and due to the reduced soil compaction the microbiological fauna and the soil porosity will be undisturbed leading to a healthy soil with god cultivation potential and safety.

This type of integrated self-propelled integrated compact tooling systems, also fit well with the concepts developed for small plant caring robots. Due to the integrated design and the available geo positioning systems, it is possible to map and follow the crop and local growth pattern. Even when the placement of the single seeds is mapped, the uncertainty is so big, that it is not possible to relocate the spots only by geo positioning. Although, from a control engineering point of view a substantial benefit is achieved from a first approach to locate individual plants or rows. In this case, good conditions for robot based plant care and individual or spot based plant care, row cropping etc. are established. This system can also corporate with systems with fixed tracing tracks or even fixed positioning of crop rows.

This type of coming redesigned agricultural tooling systems will display a quite new design also in relation to interaction with the operator. As in big industrial tool units, an operator is needed to oversee the process and to optimize the performance if needed. The system will be flexible as to where the operator is located. If this is on the implement or at a control unit decoupled from the working unit, will be up to an analysis of the best performance and the potential of controlling more units.

One of the difficult topics to forecast is the sizing of such redesigned units. It cannot be too small due to the fact the working capacity has to balance the cost of the components on the implements. Goense has analyzed this topic (Goense, 2003). He states, that in general, the optimal working width for autonomic systems are smaller than for manned units due to the absence of labor costs. In an example for inter row cultivation, the result shows an optimum between 4–10 meters of working width, depending on the costs for the navigation and control system. The decision upon size will also depend on limit max weight or maneuverability.

Autonomous self-propelled vehicles also include a big potential in the planning, routing and collaborating between different vehicles. The potential of a swarm of small collaborating weeding robots are described by several authors. The goal could also be logistic optimization e.g. in the process of fertilization by slurry distributions. In operations as this using today’s technology much traffic is necessary for transporting drive on the field without operating the implement. This could be optimized by arranging a dedicated tracking system and by having units which continuously operate the distribution and other which deliver the slurry or other materials to the dispersing implement distributing the material over the field.

In general, this will be a change of paradigm for agricultural machinery. Experience shows, that when such new technology is available on the market, the demands from the customer changes, and the working method for the customer changes to utilize the new possibilities in new optimized systems. In this sense, an iterative approach arises where the supplier and the customer together adapt the solutions to get the best possible benefit from the new technology.

Results and discussion

As described, the hypothesis is that new technologies and engineering knowledge are available to perform a change in the paradigm of agricultural machinery. The prediction is that agricultural field machinery will be redesigned into integrated compact and harmonic units dedicated for the different operations in the growing system. The expectation is, that this will lead to a cost effective system with a low environmental impact. To obtain it, is necessary to establish the agronomic needs for the different operations. Some of these are described and available for the design of the dedicated implements. In many cases, however, the sensor input to the implement will be indirect in relation to the physical or biological need. In this sense, a lot of research is still needed to enable specification of data for the optimal operation.

It seems, that the technological elements and engineering basis are available to design self-propelled auto guided integrated tools, which will demonstrate improved working performance in the field and be economically attractive for investments by farmers. The very important question is, as always, the size and the time to market.

Conclusions

It can be concluded, that the technology is available for applying agricultural tractors as autonomic units. If it is believed, that this development will progress, it opens for engineering development processes, as expected, for other industrial machinery or tooling systems, where the units has been redesigned drastically, to benefit from the possibilities that opens with the concept of self-propelled autonomic tooling systems.

In this way, the possibilities are open for designing new integrated tooling systems, which can lead to optimization of the economic output from agricultural field production and, at the same time, lead to a reduced environmental impact compared to what is seen today.

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