Machine Diagnostics in scope of the LaSeKo Project

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Abstract
Agricultural processes have to comply with ecological, economical and political demands. Especially the tracing of food is important for consumer protection. At the same time reducing costs is necessary for farmers to be competitive. Machine up time is a critical factor, especially in processes that are reliant on short, whether-depending harvesting slots. Based on a mobile electronic system, the project consortium of the LaSeKo-Project is developing an autonomous agricultural communication system for the traceability of crops and harvesting batches that simultaneously enables for online machine diagnostics and a remote maintenance concept.

Keywords
ad-hoc radio network, harvesting process, documentation, machine diagnostics, remote maintenance, Contact & Channel Model, strain Index

1 INTRODUCTION TO THE LASEKO-PROJECT

The translated meaning of the German acronym “LaSeKo” stands for “Agricultural Ad-hoc Communication System for the Surveillance, Optimization and Documentation of harvesting processes”. The project is the succession of the ESOB project. The basic idea of that previous project was to develop and evaluate a system to control position and condition of mobile working machines, containers and accessory equipment in the construction industry [1]. Due to a regulation of the European Union, the product liability law for food, the development of a documentation system for the entire harvesting process is obligatory. Based on the mobile electronic system developed in the ESOB project, the LaSeKo consortium is developing a technical approach to connect independent network devices and machines for the collection of process data, control and diagnostic purposes. The main item of the system is a private area network (PAN) module controlled by a microcontroller. On the basis of IEEE 802.15.4 wireless standard, the system is able to autonomously establish a network. The communication units (LaSeKo-Boxes) act independently. They comprise different interfaces e.g. two CAN interfaces, a GPS receiver and, if required, an additionally fitted GPRS port for data transfer via Internet. All combines and tractors of a harvesting fleet will be equipped with a communication unit (LaSeKo-Box). In addition to the technical details of the LaSeKo-Box, this paper focuses on possible applications in the field of machine diagnostics.
The wireless data transfer can be used for a universal agricultural documentation system. Site specific harvest data as well as further crop data can be transmitted from the LaSeKo-Box of the combine harvester to the LaSeKo-Box of the transport vehicle simultaneously to transferring the crop. Thus, the transport vehicle transfers all information about the crop, e.g. its geographical growth position, the harvest quality, the harvesting time etc. This data can afterwards be transferred to the following crop processing stages, setting up a complete information chain, ending with the consumer as final destination. However, drawbacks might be the size of the considered crop batches and the potential mixing of different packages in the crop elevator, impeding clear retracement.
By collecting data it is possible to visualize and simulate the harvesting process in the farm office. As a result, human and machine resources may be used more efficiently. Furthermore it is possible to save the data in field record systems and to implement the autonomous documentation for cross compliance. Additionally data can be transferred between other software programs according to the agro-XML standard [2].

The LaSeKo project is funded by the German Federal Ministry of Food, Agriculture and Consumer Protection. Project partners are the Karlsruhe Institute of Technology (KIT), TU Dresden and TU Berlin plus the companies LogicWay, SimPlan, Arkade and John Deere AMS Europe. Among these partners the project tasks are distributed as follows: The project coordination as well as the software development for the communication-unit (LaSeKo-box) is carried out by the researchers of TU Berlin. The hardware, i.e. the communication-box itself, is developed and produced by LogicWay. John Deere AMS Europe provides an interface to enable the communication between the proprietary combine BUS system and the LaSeKo-Box. At the KIT scientists are determining the possibilities to predict failure of components based on the gathered data. SimPlan and Arcade are developing the master control station and the required central and local databases. Furthermore, SimPlan is in charge of the development of the tools to visualize and simulate the harvesting process. Field testing on John Deere combines is carried out by TU Dresden in close cooperation with John Deere AMS Europe.

2 LASEKO-BOX INTERFACES

Figure 1 depicts the block diagram of the LaSeKo-Box with interfaces. The AP7000, a 32-Bit processor manufactured by Atmel, was chosen as microcontroller. The operating system is a Linux to control the running processes. By using additional software modules, it is easy to implement real-time applications. The AVR32Studio 2.1. serves as an integrated development environment (IDE) to write and cross-compile the applications.

For the radio interfaces the Atmel AT81RF231 serves as an IEEE 802.15.4 standard compliant chip. With a theoretical data rate of 250 kbauds, it can handle data volumes up to 50 Mbyte per day. But since only machine data need to be transferred, the installed transmission capacity is sufficient. The chosen radio standard is free of provider charges and the costs of implementation are low. [3]

The communication box receives the position data from the Sirf III GPS chipset. This data string does not only contain the position but also a time stamp which can be used for cluster synchronization. At the same time, the box receives information about the GPS signal's intensity and the number of satellites within reach. These data are analyzed and marked for comparison.

The communication-box uses the CAN interfaces to collect data of the connected machine, being able to recognize and forward the machine status. In most applications, the communication is done via SAE J1939 standard for Diesel aggregates or via the ISOBUS according to ISO 11783 for tractors and agricultural machinery. On the one hand the LaSeKo-Box collects crop data, e.g. quantity, quality, humidity. On the other hand it works as diagnostic device, analyzing important data such as maintenance intervals, speed, operating hours or error massages. With the help of these data, the farm office is always aware of the current machine condition. [4]

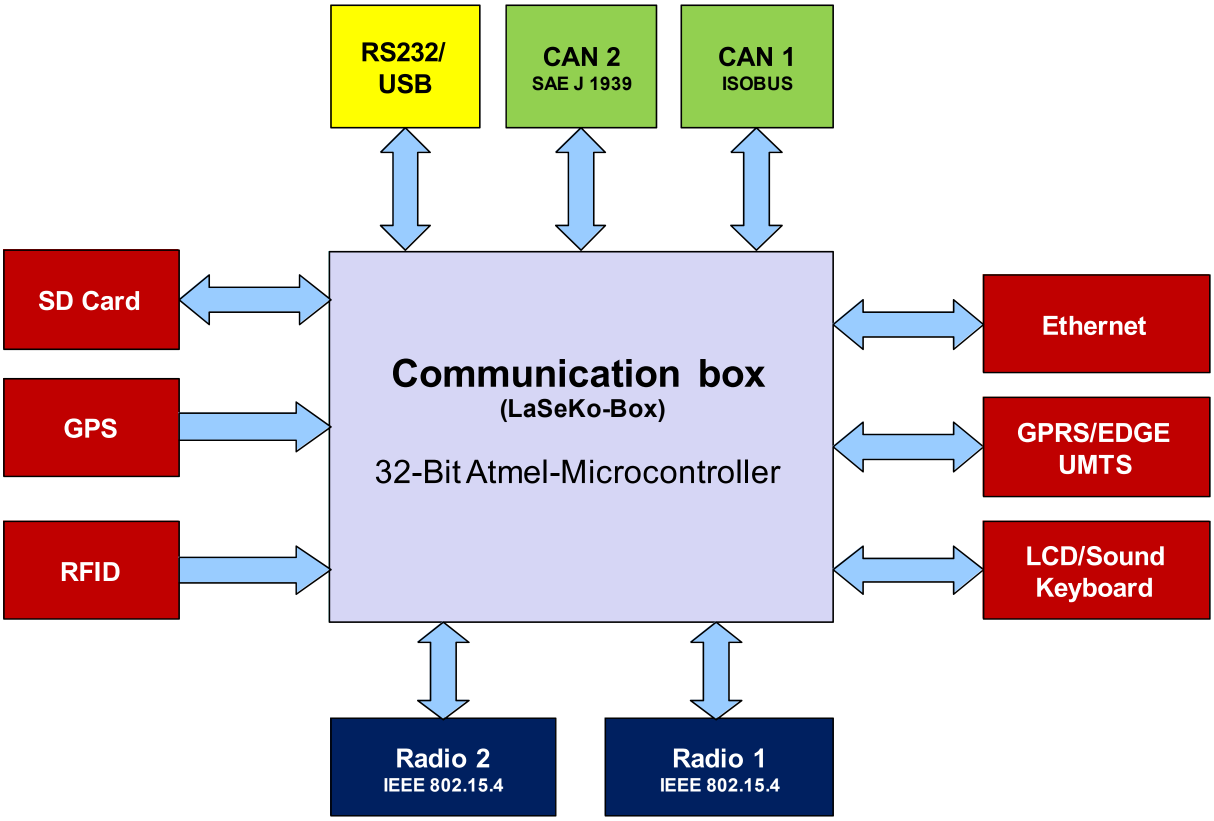

Figure 1: block diagram of the communication box with interfaces

The collected data are buffered on an SD card. In addition, it is possible to identify a machine operator by the SD card. Furthermore all data packages have a time stamp, thus it is always possible to retrieve the latest data. The data are decoded and compared. In fixed intervals, the server sends the data of the entire cluster to the farm office. The common data format is XML.
Via the GPRS/UMTS/EDGE module, it is possible to send data from the machine directly to the farm office. This is done by a provider and is subject to data transmission charges. As an estimated average transmitting time of 30 minutes for a data package via the crop transportation vehicles is presumed, only time critical data shall be transferred via GPRS/UMTS/EDGE.
With the RFID interface it is possible to identify a machine driver to enable accurate accounting of working hours and machine handling times. With RS232/USB-interfaces additional sensors or memory may be controlled.
To establish the communication between the radio network and the database a communication box is installed on the farm and connected via Ethernet. Additionally a WLAN interface has been developed to connect the LaSeKo Boxes on the machines to a notebook. This is a grand benefit in the development phase because the machine does not have to be stopped to broadcast data and to reconfigure the setup online.
The LaSeKo system is autonomous, thus no man-machine interface is required. Nevertheless, to realize a flexible system, LCD, Sound and Keyboard interfaces are integrated.

3 NETWORK AND SYSTEM CONFIGURATION

The transmission power and thereby the radio range of the single radio modules are limited. Therefore data have to be carried by the crop transportation vehicles. The data transmission between the working machines and the central file server is displayed in figure 2. This figure points out the process of the data transport from a combine to the fileserver. Process data, i.e. position, humidity, etc. are handed over simultaneous to the transfer of the grain. Hence the vehicle or equipment to which the data has been transferred, in this case a tractor with two trailers, keeps the information about its load and carries it to the silo. The vehicle additionally records its route, error messages and fuel consumption

during the transport and assigns the information to the process data. The whole data is passed to the central fileserver and allows later backtracking of the harvest.
To ensure rapid data transfer to the central file server and to prevent inefficient loops, a waterfall architecture has been developed. The process participants along the harvesting chain have decreasing priorities. Data flow is limited to downstream direction, acknowledgements vice versa. Data packages are stored at their source until the date server has acknowledged the delivery. Unacknowledged data packages are being resend at intervals of several hours.

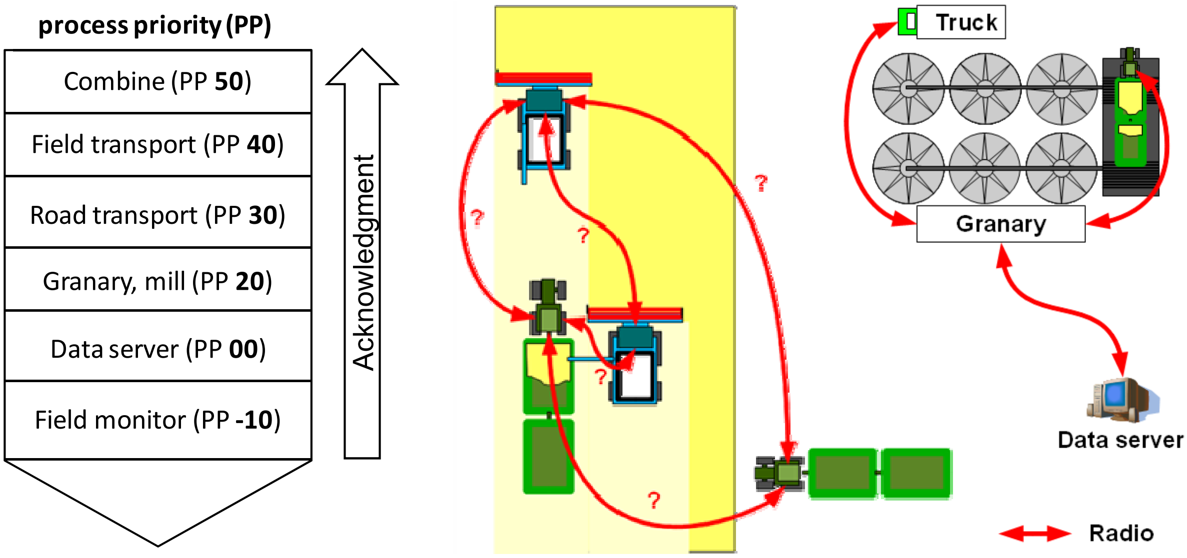

Figure 2: data handling along the harvesting chain

Furthermore figure 2 shows the problems that might occur while choosing between two process participants of the same priority. There has to be a fail-save data communication. In case of a third vehicle coming within range of the radio network, the data could be passed to the wrong device, concluding in an inaccurate assignment of the particular crop batch to the trailer. This is prevented through the usage of directional radio antennas and continuous signal strength monitoring.

4 MACHINE DIAGNOSTICS

The LaSeKo-Box gathers process and machine data. The monitoring of these machine data, accompanied by selected sensor data, may be used to predict the failure of components. Through the data transmission via the communication-boxes, a remote maintenance becomes feasible.

4.1 Methodology

The scientific approach to machine diagnostics shall be accomplished by means of the Contact & Channel Model (C&CM), introduced by Matthiesen [5].
This method allows for the development of a general methodology, valid for various types of mobile machinery. It is based on a theoretical model, which links the abstract level of functions of a technical system to the concrete level of shape. Working Surface Pairs (WSP) and Channel and Support Structures (CSS) are the basic elements of this model and they define the interface between these two abstraction levels. Due to the abstract definition of these terms, the C&CM may be applied to solid structures as well as to fluids[1] and fields. [6]
The Working Surface Pairs are the surfaces of a technical system through which system parameters, namely material, energy and information, are transmitted. Therein the contact may be permanent, periodic or stochastic, analogue to the accomplished function.
Channel and Support Structures connect exactly two Working Surface Pairs. They transmit the system parameters material, energy and information from one WSP, through the structure, to the next.

[1] *fluid* shall per definition represent liquid and gaseous media [8]

Furthermore they have the ability to store these system parameters. Apart from the obvious storage of hydraulic or electrical energy, also the information about e.g. damage and component stress is inherent in CSSs. This is where machine diagnostics cuts in.
The C&CM enables engineers to reduce problems to basic principles and think about them in an abstract form that is well anchored in its figurative representations without losing reference to the geometrical representation of the system. Analysing the existing system in terms of C&CM draws the attention to functions and their realisation, which is difficult to distinguish in other models that do not combine functional and geometric descriptions. [7]
Another advantage of the C&CM is its scalability. The resolution regarding a system does not have to be constant in each and every detail throughout the entire system but can be chosen variably depending on the focus of interest. The system may be reduced to the WSPs that are concerning the respective interaction. Due to the standard interface, the WSP, the level of detail can vary in a single illustration. If only the interaction with the environment is concerned, the entire system is represented by a Black Box CSS and the according WSPs. A deeper look is provided by the segmentation into subsystems (see fig. 3). Units like the engine, the drive train, the threshing organs, the straw shredder and the harvesting header are represented by corresponding Black Box CSSs that are linked with WSPs.

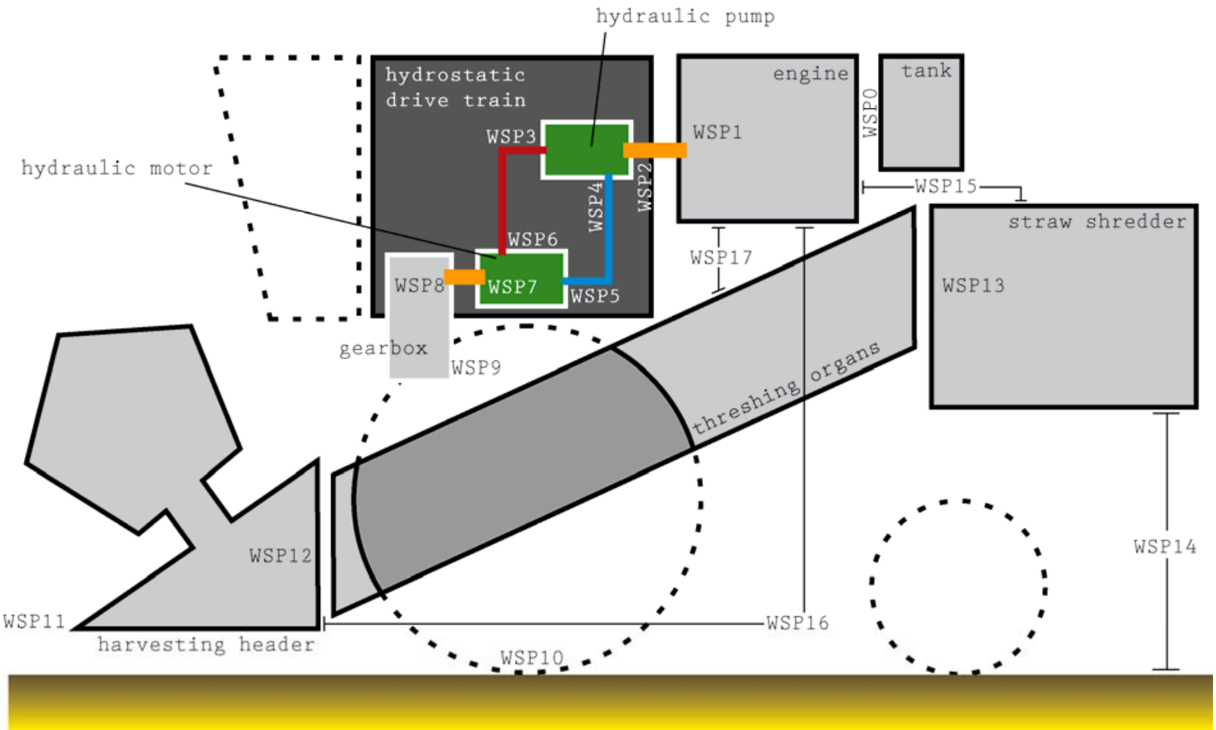

Figure 3: combine in C&CM layout

The engineer gains profound insight into a subassembly if divided into the WSPs between its parts. This is the most intuitive level of abstraction [7]. Even more details of functions can be described using a micro-resolution of the system. In this context the LaSeKo-Box may serve to record load spectra leading to an optimized product design.

4.2 Strain Index

The accumulation and interpretation of the gathered machine data allows for the definition of Strain Indices (SI) for the regarded assembly groups and as average value, the calculation of a Global Strain Index for the entire contemplated technical system, respective the combine harvester.
Together with the monitored operating time or distance, a failure prognosis for individual components may be calculated of the Strain Index.
In contrast to common condition based maintenance (CBM), requiring the continuous state-of-wear surveillance of every critical component, and to fixed-scheduled interval maintenance models, the introduced extended preventive maintenance (EPM) concept, based on strain indices, represents a

cost-efficient maintenance. On the on hand failure of heavy strained components is prevented. On the other hand maintenance intervals of light strained components with reduced wear-out are prolonged. (see fig. 4)

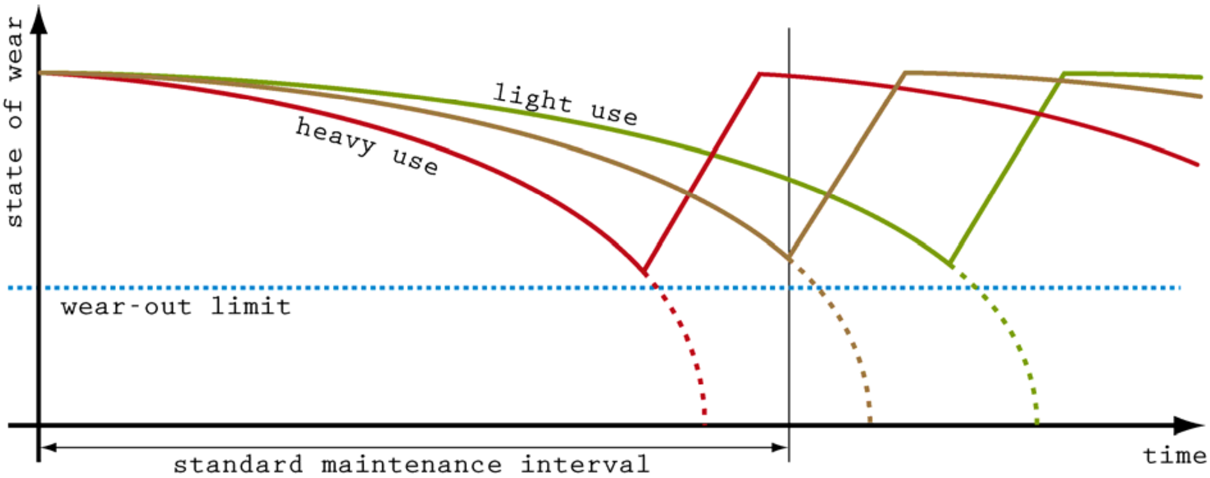

Figure 4: extended preventive maintenance concept

The LaSeKo-Box collects data that, on the first sight, are not directly involved in the task of machine diagnostics but, through the interpretation of aggregated data sets, the immanent information helps to assemble a complete status of the machine condition.
For example the monitoring of the pressure in the hydrostatic drive train, backed up by the recorded GPS track (through the underlying altitude indication) may be utilized to determine whether a harvester is employed mainly on flat areas rather than in hilly terrain, especially straining the drive train. Opposing the peak loads of the threshing organs that occur when harvesting wet or high density crops that are indicated by several sensors and setup values. Namely the grain moisture and throughput meter as well as the type of corn. Even the harvesting time throughout the day or year depicts valuable information in that context.
Moreover the incidence of single events of maximum strain may be integrated into the Strain Index. The abrupt stoppage of the threshing organs indicates a blockage, highly staining their drives. Maximum torque on the hydrostatic drive train, fast rotating wheels but the combine only moving slowly back and forth (GPS) represent a driver trying to free his machine that got stuck in muddy grounds.
These examples illustrate the possibilities offered by the LaSeKo-Box in terms of machine diagnostics. The performance of the unit allows for a complete monitoring of the harvester functions in the required CSS scale. Through the ad-hoc network, remote maintenance tasks may be requested on demand and autonomous.

4.3 Validation

To demonstrate the performance of the LaSeKo-Box in scope of the project, the hydrostatic drive train of a combine harvester is selected. This subassembly is extraordinary suitable to display the versatility of the Box whereas its power may merely be assumed. The main components are the hydrostatic pump, the hydrostatic motor and the hydraulic fluid. Various aspects of maintenance are highlighted (see fig. 5).

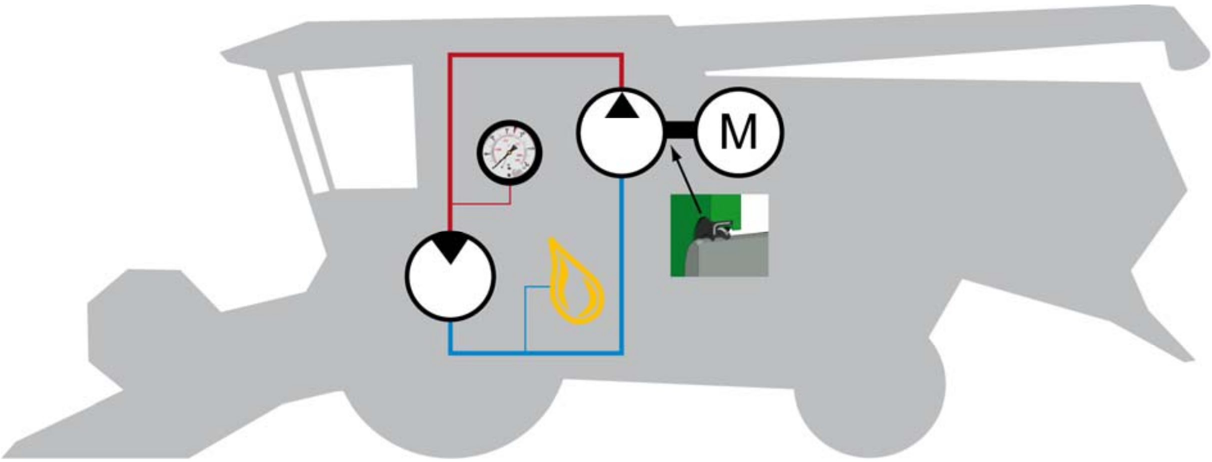

Figure 5: hydrostatic drive train

Besides oil quality and system pressure, being determined by additional sensors, other parameters are calculated by data fusion of existing CAN-BUS massages.

Oil Quality
The oil quality will be detected by an oil multi sensor being installed in the oil circuit and connected to the LaSeKo-Box via CAN-BUS. The device consists of a particle counter, a water sensor, a thermometer and sensors to measure oil viscosity, dielectricity and conductivity to detect air, mixture and shear strain. This data set is processed, the oil status is compiled and, if required, maintenance arrangements are being appointed autonomously via the LaSeKo-network.
The LaSeKo-Box is not only capable of determining the current oil status but as well of calculating a value for the average oil quality over time, allowing for assumptions about the status of components being operated with contaminated fluid.

Pressure
Occurring pressure peaks impair the components of the hydrostatic circuit and accumulate to a failure. The oil pressure is monitored by the LaSeKo-Box and the peaks are added up. If the resilience of e.g. a hydraulic pump is known, the probability of failure occurrence may be predicted.

Sealing
Radial shaft seal rings represent important components in scope of the reliability of a technical system. Due to critical stress in consequence of friction, wear and high temperatures as well as complex interaction between sealing, shaft and fluid, unfortunately a reliable mean failure rate prognosis of these tribological systems is not yet possible [9].
In the LaSeKo-Project, researchers propose to integrate the running distance of a sealing over its life cycle. Multiplied with an appropriate strain index (SI) the reliability may be calculated and the required maintenance can be carried out before a severe failure occurs. (see formula 1)

Formula 1: $$SI \cdot 2\pi \cdot r \cdot \int_0^t n\,dt \leq \mathrm{MTBF}_{\mathrm{sealing}}$$

Diagnostic Trouble Codes
The LaSeKo-Box monitors the machine-BUS. Diagnostic Trouble Codes that are commonly displayed to the operator to inform him about appearing faults may additionally be transmitted via the LaSeKo-network to the machine owner or directly to the authorized maintenance provider. Through that the service technician can perform a remote fault diagnosis leading to a reduced down time.

4.4 Perspective

In addition to the optimized machine-maintenance, the output of the LaSeKo project provides a development tool for machine manufacturers. Furthermore it depicts a step towards the setup of a knowledge database about the workload of agricultural machinery, which is a profound objective of the researchers of the Institute for Mobile Machines at the KIT.

5 CONCLUSIONS

This system allows the controlling and documentation of the entire harvesting process, visualizing and preparing data for farmers and contractors. In context of machine diagnostics the system may be used to implement a remote maintenance concept. Leading to increased machine up time in the short harvesting season and decreased financial risks for machine manufacturers on availability guarantee contracts.
The benefits of the LaSeKo communication system are its low costs of implementation and its subsistence free of transmittance charges for communication providers.
For a reliable and secure data transmission between mobile working machines and a data server, new data handling mechanisms are being developed. These mechanisms have to consider the particular agricultural applications, constraints and conditions.

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