REMOTE MAINTENANCE OF AGRICULTURAL MACHINES

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Abstract: The goal of Agrix-project is to develop a prototype of an open, generic and configurable automation platform for agricultural machinery. A typical configuration consists of a tractor and one or several implements. Fault tolerance and remote maintenance over mobile networks are essential research topics due to short seasons for agricultural operations especially in Nordic countries. The main purpose of realizing the fast-prototype of the control system in 2003 was to get acquainted with the problems occurring in working with agricultural machines. Experiences from the fast-prototype, some initial tests to realize the mobile communication system and principles of remote maintenance are reported in this paper. The agricultural implement selected for the fast-prototype was a combined seed and fertilizer drill. The tractor was equipped with ISOBUS compatible electronic control unit. A commercial CAN-controller with a high-power digital and analog I/O interface was used as the implement electronic control unit. The architecture of Agrix fast-prototype was designed according to ISOBUS (ISO 11783) standard. *Copyright © 2004 IFAC*

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1. INTRODUCTION

In precision farming, cultivation operations, timing and the amount of cultivation material inputs, are adapted to local optimal values relative to the needs of the cultivated plant in accordance with the soil characteristics and nutrient content. The information needed for adaptation comes from laboratory analysis of soil samples taken from planned positions of the field block, other position based measurements and observations of the field, e.g. crop measuring in harvester machine.

Farm information management system (FIMS) is used to manage the position attributed measurement information. The cultivation operations and set point maps for different cultivation inputs are planned with special computer programs in the farm office or in the companies providing precision farming services. To execute the output of these “computer aided cultivation planning systems”, position based control systems are needed. A typical agricultural machine system consists of a tractor and an implement. With position based machine control system, the driver can operate and control the machinery during cultivation manoeuvre. The system can automatically control the planned variables, like the feeding rate of seed and fertilizer in drilling, to position dependent planned set points. The goal of Agrix-project is to develop a prototype of an *open, generic* and *configurable* automation platform for agricultural tractor – implement systems. Also *fault tolerance and remote maintenance* are important research topics.

The optimal time period for specific cultivation operations is very short in Nordic countries. The machine control system and the machine itself should be as reliable and operable as possible during this hectic season. If various faults occur, they should be detected, diagnosed and repaired quickly so that that machine can be operational as soon as possible and the cultivation can be continued. Even in the worst case it should be possible to get system into a state in which it can be safely moved from the field to a repair shop. The wearing should be detected before damages, if possible. If these generic machine control systems are used widely enough there will be markets for remote maintenance and repairing services. These services can be provided via the public mobile communication networks, like GSM and later UMTS. The service provider could analyse the faults on-line based on the state information send automatically by the machine control system. After analysing the data the service provider can advice and support the farmer in repairing the machine. It would be even better, if the faults could be prevented with by analysing the early symptoms before the device brakes down. This kind of *fault tolerance*, *remote fault diagnosis, support* and *remote maintenance* is one of the essential research themes of the Agrix-project.

Open system interconnection means that international communication protocol standards are utilized in order to get the control units of different tractors and agricultural implements from different vendors to communicate with each other. The idea of Open System Interconnection (OSI) comes originally from the ancient ISO standard 7498 ISO (1984). The reference model defined in this standard has been used very widely and it also forms the conceptual basis of the ISO 11783 standard (ISOBUS 2003), which is currently under development.

Generic control system means that it should be possible to use the same automation platform to control different machines, in this case agricultural implements.

Configurability means that control functions can be defined with high-level, usually graphical, tools instead of programming with low level programming language, that are still commonly used in embedded machine control systems. However, in industrial automation applications, high level, graphical configuration tools are widely used and complex system are built from reusable components.

The three-year Agrix-project is introduced at first. The main purpose of realizing the fast-prototype control system in 2003 was to get acquainted with the requirements and problems related to tractor – implement control systems. The experiences gained in implementing this first version, fast-prototype control system, are reported.

2. THE AGRIX-PROJECT

Agricultural environment is challenging for automation. The usage of crop farming machinery is usually seasonal except tractors. Machines are stored inside most of the year and are used only some weeks yearly. The storage conditions are harsh especially in Finland as the temperature varies according to the outside temperature during the year, which may cause problems for the electronics equipment in the machines. The moisture variations are wide but smooth due to the roof and wall of the storage and usually there is also a water barrier in the floor. However when the working season becomes, the machine should work reliably.

The total production volumes of agricultural implements are small in Finland. The sizes of production series are small because many different product variations are available. Therefore the control system for implements needs to be low cost. In addition to real-time requirements, working security and reliability are needed as well.

The goal of Agrix-project is to develop a prototype of an open, generic and configurable automation system platform for tractor – implement systems. The platform should be easily configurable to different implements and it should have configurable remote diagnostics and maintenance functions. Currently, the commercial control systems for agricultural machines use tailored embedded software. Their configurability varies from non-existent to very limited. The software is implemented with C or assembler programming language. This kind of approach requires large series in order to be profitable.

2.1 Tools for control software

The configuration tools should support the new standards for automation or real-time software development. One possible standard could be the IEC-61131, which has established itself as a standard notation for developing PLC-type industrial applications. A good text book about the use of IEC-61131 has been written by Lewis (1998). However, the functions of the agricultural implants can be quite complex to be implemented easily with this logic standard. The emerging IEC-61499 function block standard tries to address these limitations and seems to be sufficient software development platform for modern automation applications, see references Lewis (2001) and Christensen (2000). However, the commercial support for this automation standard is still quite limited. Constellation development tool set by RTI Ltd (2003), in which applications are defined or configured with real time UML, is used as software tool for the next version of Agrix-system. UML standard is widely used for software development in general, see e.g. OMG (2004). It has also extensions for real-time systems. With Constellation it is possible to make function blocks, which can be quite similar with IEC-61499 function blocks.

2.2 Communication standard for Agricultural Machinery

The commercially available control systems for agricultural machines have been mostly incompatible. There have been only national standards for communication between tractor and implement control systems. The lack of an open international standard is alleviated by the new ISO 11783 standard, named as "The New Standard for Agricultural Machinery", see e.g. VDMA (2001 and

2002). The standard is based on national standards, both German DIN-9684 and American SAE-J1939, so the standardization process can be said to be global and therefore believable. The standard contains now 7 final parts and at least 6 parts are still on development. The ISO 11783 standard, also known as ISOBUS, has CAN-bus at the physical layer and medium access control. The communication between electronic control units (ECUs) connected to the bus (tractor, terminal, implements, task controller, positioning device, file server) is going to be standardized and also the communication between the control system and the farm information management system.

ISO 11783 Part 12 deals with diagnostics. This work is in early phase and will contain definition of external diagnostic system connected to the ISOBUS CAN. The research in Agrix-project on remote diagnostics and maintenance could be utilized in this standardization work in later phase.

2.3 Precision farming

Precision farming also plays an important role in Agrix-project. Precision farming means that local variation in soil and other condition in the field are taken locally into account by changing certain feeding set points and working parameters to planned optimal local values according to the position measurement in real-time.

2.4 Telematics and remote maintenance

Remote fault diagnosis and maintenance in agriculture was already introduced above. It is dealt with more in detail in following sections, particularly section 5.

2.5 Positioning

The accuracy of basic GPS-receiver is suitable for precision farming purposes, but more precise positioning is needed for navigation and steering with autopilot. The precision of standard or differential GPS can be improved on the basis of dynamic vehicle model and additional measurements with cheap sensors which measure local properties, like land radar measuring velocity, inertial navigation sensors, i.e. acceleration sensors and gyroscope, electronic compass and velocity and direction of machine wheels. By combining these different measurements using model based sensor fusion, it's possible to improve the precision of positioning.

2.6 Wireless communication

Wireless communication especially between tractor and implement could reduce the connector problems, which has been found to be one of the main reasons for electronic failures in agricultural machines. Power cables are needed in any case, of course. Commercial large volume WLAN (IEEE 802.11b) modules are cheap, in some cases even cheaper than implementing the physical layer with cables and connectors.

2.7 Driving lines and field traffic

Optimal planning of driving lines and field traffic is a little bit separate methods research area. The aim is to plan the movements in fields optimally, the criteria contain time, the usage of fuel, distance travelled, the quality of work result, soil compacting, etc. The conditions are the field (e.g. size, shape, obstacles, entrance, exit), and the machine (e.g. task, width, agility, tank size).

3. AGRIX FAST-PROTOTYPE

Agrix-project was started effectively May 2003. It was decided to make a fast-prototype of automation system for agricultural implements in order to get familiar with specific problems occurring in agricultural machines. All the requirements set in plans were not included into fast prototype requirements. One of the most important requirements in the whole project, the configurability was dismissed in fast-prototype. The demonstrated fast-prototype version was not a generic control system, easily configurable with high level tools in connection of different implements. Only one implement case was selected and the programs were made using pure C-language. The fast-proto was operational in autumn 2003 after four months of hard work.

The machine platform selected for fast-prototype was a combined seed and fertilizer driller, shown in Figure 1. The tractor was equipped with ISOBUS compatible tractor ECU.

Fig. 1. Combined seed and fertilizer driller.

The existing control system was removed and some measurements added. For example, the levels in the two containers, for seed and fertilizer; the height of the front leveling board and the coulter position (actually pressure on the field) can be measured with additional sensors. The seed and fertilizer feeding rates are controlled to planned spatial reference points on the basis of positioning with GPS. In ISOBUS architecture, each implement has own ECU as well the tractor has own ECU. The implement controller ISOBUS ECU was implemented with a commercial CAN-controller. Controller has plenty of inputs and outputs, both digital and analog. Outputs are 12V / 2A, so most of electrical actuators can be controlled directly. The controller is based on

Motorola's 32-bit 68376 microcontroller with on-chip CAN-controller.

The controller program was written in C-language and it was compiled with gcc in Linux environment. Even if the configurability for several implements was dismissed and the program was written in C, the program was designed in an object oriented manner. The functionality of the seed drill was divided into components which each handles a separate action. In spite of pure C, object oriented design was used as much as possible for later use.

Most actuators for control of the seed drill are hydraulic, powered by tractor's hydraulic system. In the original version the hydraulic actuators were coupled in a way in order to save the number of hydraulic valves needed from tractor. Even if this coupling was made quite easy to understand, it was quite difficult to handle with computer controller. The original hydraulic system in the drill was replaced with a new electro-hydraulic valve block, with which all hydraulics could be controlled separately.

The architecture of Agrix fast-prototype, shown in Figure 2, was designed according to ISOBUS, ISO 11783. Three physical ECUs were connected to CAN with ISOBUS upper protocol layers: Tractor ECU, Implement ECU, Terminal (Virtual Terminal VT + Task Controller TC). Laptop-PC was also connected to bus, for logging and analyzing purposes. At this phase, any separate ISOBUS VT (Virtual Terminal) was not used.

In industrial automation, standard, inexpensive PCs are used as HMI (Human Machine Interface). Accordingly, it was tested if an inexpensive standards PDA or handheld (HP iPAQ) could be used as HMI or user terminal for the implement. The connection to ISOBUS were made using CAN-PC Card. The programs for PDA were made with Microsoft tools for PocketPC 2002 operating system. The user interface in handheld is quite small and limited if something else is going to be done at the same time (like drive a tractor).

To improve the operability an external control keyboard was connected into the PDA. Both the VT (Virtual Terminal) and TC (Task Controller) software were running in the PDA. Afterwards it was discovered that some of the processing power problems were due to the standard, non-real-time PDA operating system. The CAN-driver also required plenty of processing power when the bus traffic was high. The CAN-driver for PocketPC did not support hardware filtering of incoming messages. The GPS receiver was connected to the PDA with Bluetooth^{TM}. For most of the time the Bluetooth worked fine. But occasionally the connection failed and re-establishing it required multiple reboots.

The standard office PDA with cover and external keyboard are in shown in Figure 3. There are also more rugged PDAs for outdoor use, which would be more suitable for this kind of use.

Fig. 2. The ISOBUS architecture in Agrix Fast-proto system.

Fig. 3. The HMI implemented with standard PDA and external keyboard.

The HMI software contained eight different graphical displays for monitoring and operating the machine. For different alarm and emergency situations there is a separate display. In manual mode, all actuators can be controlled separately: the control functions of the coulter unit attached to the 3-point hitch of the hopper unit, the height control of the levelling board, tramline functions, marker functions, hopper capacity, blower monitoring. The automatic mode contains several sequences: starting for starting the run, for ending the run, marker control and tramline control. As example only one display is shown here. The main operation display, illustrated in Figure 4, shows velocity, drilled area, the hopper capacity, marker and tramline state, and easy entrance to the most common functional displays. Almost all imaginable operations are implemented, and the number of measurements is the widest reasonable.

4. THE FIELD EXPERIMENTS

The Agrix fast-prototype was finally tested in real drilling of wheat in the experiment field of 6 hectares. There were some problems in localization and for this reason the feed rate was not always controlled to right values. The PDA software required occasionally more processing time than what was available. However, for the most time the system worked as planned. The experiments were executed at the research farm of the Agricultural Engineering sub-unit (VAKOLA) at the MTT Agrifood Research Finland.

5. REMOTE MAINTENENCE

In telematics, wired or mobile communication services, private or offered by communication operators, are utilized in remote operation or support of industrial process, machines or devices. Telematics applications, remote fault diagnosis, service and maintenance were at first implemented in connection of space and military technology but civil applications in connections power plants, paper machines, community technology and e.g. in elevators emerged in the 1990's as part of so called extended product concept. There exists commercial remote service centres for monitoring and diagnosing over different kind of networks not only paper machines and power plants, but also certain quite expensive agricultural machines, like e.g. potato harvester Grimme (2003) and forestry machines Ponsse (2004). In this project, remote maintenance will be realized in connection of low cost automation in agricultural implements.

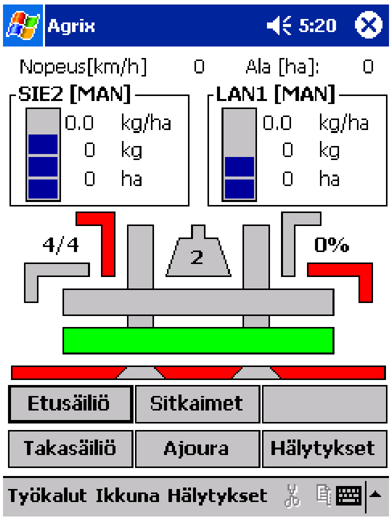
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Fig. 4. The main operation display.

5.1 Communication link and service provider

In Europe, the only way to realize a communication link from the machine unit in the field to the service provider far away is via the public mobile communication networks, data transfer protocols over GSM and later UMTS; WLAN will probably never cover the whole countryside due to the quite short coverage.

An experimental test system has been realized. In this scheme, the communicating element in Agrix-system is a PDA (Compaq iPAD), which is either connected via Bluetooth with a GSM mobile phone (Ericsson R520) or alternatively has itself GSM/GPRS PCMCIA-card. The GSM device communicates over circuit based GSM-data or packet based GPRS with the service provider, a PC, via internet as client-server using sockets as interface. The data needed in remote maintenance can be transferred between PDA and service provider over GSM and Internet.

This service provider could analyse the faults on-line based on the state information sent automatically by the machine control system. After analyzing the data the service provider can advice and support the farmer in repairing the machine. In the fast prototype these remote services were not yet implemented. This will be done in summer 2004 with the basis Agrix-system realized in spring/summer 2004.

It is worth noting that remote Internet servers communicating via mobile networks with Agrix-system will be demonstrated in the context of quality control and traceability of the agricultural operations. This system can be likely utilized as the platform of remote maintenance as well. Many farmers probably don't like this kind of centralized "big brother" control of agricultural operations; most farmers will plan and record the executed operations in their own farm PC. However, dislike of centralized quality control systems does not likely mean dislike of remote maintenance, if it works well and proves to be useful. The key feature in making this kind of commercial remote maintenance profitable is that the system becomes a real commercial generic platform, which can be configured to several different implements, in order to increase the amount of installed units high enough.

5.2 Fault diagnosis and telematics in Fast Proto

The realized fast prototype contained some functions for simple fault diagnosis and fault tolerance. All measurement and actuator type were analysed in order to find certain systematic ways to utilize logical redundancy i.e. to calculate or reason the status on the basis of other sensors, just monitored elapsed time or just the situation.

The Agrix Fast Proto contained checks and alarms for (interrupt of) data transfer in CAN-based ISOBUS, (low limit of) angular velocity of the blower for pneumatic transfer of seed and fertilizer, (low limit for) rotation of feeding axels, (proper control of) feed rates of seeds and fertilizer, and discrete levels of hoppers for feed and fertilizer.

In automatic mode, the limits or discrete positions of certain linear hydraulic actuators were checked on the basis of proximity sensors. The time intervals required for movements are recorded. If certain limit sensor breaks down, the recorded times can be used to stop the motion if the feedback from the sensor has been detected to be broken down. The system is planned to be fault tolerant so that a single broken sensor does not paralyse the whole system; the fault can be circumvented somehow.

5.3 Fault diagnosis methods

Different kinds of dynamic models based fault detection and diagnosis methods have been studied throughout in the process automation context, see e.g. Patton *et al* (2000). The application of these methods in working machine context is difficult, because the monitored subsystems are somehow too simple SISO systems in order to utilize real logical redundancy on the basis of MIMO dynamical models. In the same way another main approach in fault diagnosis, based on multivariate statistics, see e.g. Chiang et al (2001), PCA PLS etc. seem to be "heavy-duty" in this application. In this drill case, quite simple scalar statistical analysis and classification to temporal feature patterns can be applied on analysis of possible faults in the analog measurements. The most important variable on which one could apply model based dynamical methods is the behaviour of oil pressure in main line measured during hydraulic valve control, which is measured and available. The behaviour of oil pressure is very context dependent but it surely contains information about certain faults. In the position control of hydraulic cylinders the hits on the limits can be easily detected on the basis of oil pressure peaks if the situation is known. These will be studied. Systematic and simple procedures for remote fault diagnosis and maintenance will be developed and tested. It is interesting to see what kind of measurement data and state information is the best for remote fault diagnosis and maintenance. The methods should be reliable and there should not be wrong alarms nor undetected faults.

Schedule based maintenance procedures should be developed for the start of the season. It is maybe quite difficult to innovate condition based method for real remote maintenance; changes in elapsed times may reveal some forthcoming faults in certain movements before they occur. Fault based methods are the last chance, but faults have already taken place.

6. CONCLUSIONS

The ISOBUS standard will be very important as open communication standard for machines in agriculture. It will solve real incompatibility problems. The ISOBUS seems to be truly widely supported and international, but standardization process in not yet completed. In all communication standards for industrial automation the tools for configuring monitoring and control functions are essential part of the toolset. The ISOBUS does not support configurability at all. The ISOBUS standard contain only communication protocols and format specifications for important variables in agriculture.

In the fast-proto system, the biggest problems occurred with the PDA. Its display is quite small for use as HMI. The cheap external keyboard was a bit too vague for this purpose. The processing power of the PDA was quite limited for this kind of use and real-time problems emerged in some situations. The CAN-card needs also plenty of processing power in order to handle the whole of bus traffic.

In remote fault diagnosis and maintenance sector, a mobile communication test system was realized. In fast proto phase the focus was on stand alone fault detection and diagnosis and fault tolerance. Remote fault diagnosis and maintenance has been planned, but it will be realized later in the next version basis Agrix-control system in summer / autumn 2004.

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