OPEN CONFIGURABLE CONTROL SYSTEM FOR PRECISION FARMING

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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. 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 are reported in this paper.

The agricultural implement selected for the fast-prototype was a combined seed and fertilizer drill. The original hydraulic system was replaced with a new electro-hydraulic valve block. The tractor was equipped with ISOBUS (ISO 11783) 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 standard. In industrial automation, standard inexpensive PCs are used as Human Machine Interface (HMI). Accordingly, it was tested if a standard PDA or handheld could be used as HMI or user terminal for the implement.

The Agrix fast-prototype was finally tested in real drilling of wheat. The ISOBUS standard is very important as an open communication standard for agricultural machines. However, it does not have any features to support configurability. The biggest problems occurred with the PDA. Its display is quite small to be used as HMI in a moving vehicle. The inexpensive external keyboard was a bit too vague for its purpose. The processing power of the PDA was quite limited for this kind of use and real-time problems emerged in some situations.

KEYWORDS. Precision farming, information technology, automation technology, open systems, configurability, control, human machine interface.

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. The position attributed measurement information is managed, and the cultivation operations and set point maps for different cultivation inputs are planned with special computer programs in the farm office. In order to execute the output of these "computer aided cultivation planning systems", position based control systems are needed. A typical agricultural machine 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 system platform for agricultural tractor – implement system.

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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/IEC standard 7498 ISO (1984). The reference model defined in this standard has been used very widely and forms the conceptual basis also for the ISOBUS-standard ISO 11783 (2003) used in this project.

Generic control system means that it should be possible to use the same control system platform in control of several different machines, in this case agricultural implements like drills or sprayers.

Configurability means that control functions can be defined with high level, usually graphical, tools instead of programming with low level programming languages 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 of the control system in 2003 was to get acquainted with the requirements and problems related to tractor – implement control systems. The experiences gained from implementing this first version, fast-prototype control system, are reported.

THE AGRIX-PROJECT

Agricultural environment is challenging for automation electronics. The usage of crop farming machinery is usually seasonal. 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 electronic equipment and the electrical connectors. 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. This kind of approach requires large series in order to be profitable. With highly configurable control system, the platform hardware and the software framework is same for different implements, only the control logic is tailored to fulfill the requirements.

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). Some blocks can provide control algorithms and logic, such as PID, and others have I/O and communication interfaces, for example to a tag that is stored at a memory address in the PLC. However, the functions of the agricultural implants can be quite complicated 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). IEC 61499 can be thought of as a higher level standard, since the algorithms of a 61499 block can be implemented with any of the 61131 languages (structured text, relay-ladder, flowchart) or other languages like C or Java (for an example of a 61499 based tool that supports these languages and some RTOS targets), see e.g. Steinhoff (2003) 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 is widely used standard 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 functional blocks, which can be quite similar to IEC-61499 function blocks.

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 management information system (FMIS).

Precision farming

Precision farming also plays an important role in Agrix-project. Precision farming means that local variation in soil and other conditions in the field are taken locally into account by changing certain feed rate set points and working parameters to planned optimal local values according to the position measurement in real-time. Precision farming has not yet become popular in Finland or anywhere else in Europe. The benefits of the precision farming have been known and precision farming actually practiced with mechanical equipment before the computer based control systems for precision farming were implemented. Only for some 15 years it has been possible to automate position based control and measurement, thanks to GPS. However, there are still many problems that have delayed the spreading of precision farming usage, such as high cost and usability problems of precision farming systems. Therefore, the user interface is an important research area in this project.

Telematics and remote maintenance

Telematics and remote maintenance services have been utilized successfully in connection of more expensive industrial products, like papers machines and power plants, tractors and forestry machines as an essential part of so called extended product concept. In agriculture, 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 different kinds of faults occur, they should be detected, diagnosed and repaired quickly so that that machine can be operational as soon as possible and the cultivation activity 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. If possible, the wearing should be detected before damages. If these generic machine control systems are used widely enough, there would be markets for remote maintenance and repairing services. These services can be provided via the public mobile communication networks. This kind of fault tolerance, remote fault diagnosis, support and remote maintenance is one of the essential research themes of the Agrix-project.

Positioning

The accuracy of a basic GPS-receiver is suitable for precision farming purposes, but more precise positioning is needed for navigation and steering with autopilot. There are available commercial products, which use other global positioning methods for focusing the position, but usually they cost much more than GPS-receiver and there are some extra operating costs. The precision of GPS can be improved on the basis of dynamic vehicle model and additional measurements with inexpensive 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 is possible to improve the precision of positioning.

Wireless communication

Wireless communication especially between tractor and implement could reduce the connector problems, which have 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 inexpensive, in some cases less expensive than implementing the physical layer with cables and connectors. However, it can be difficult to implement the reliable wireless communication between a tractor and an implement due to metal surfaces blocking and reflecting signals. Possibilities of wireless communication between tractor and implement will be researched in Agrix-project.

Driving lines and field traffic

Optimal planning of driving lines and field traffic is a little bit separate research area. The aim is to plan the movements in fields optimally. The optimization of field traffic can be separated into three different phases. In the first phase the initial driving plan is made off-line beforehand. The second phase is done just before going to the field with machine (the field properties may have changed) and the third phase is done in real-time during the driving. The first phase off-line optimization takes quite long time so that it cannot be done on the field.

AGRIX FAST-PROTOTYPE

Agrix-project was started effectively in May 2003. A fast-prototype of a tractor–implement automation system was built to get the familiar with specific problems occurring in agricultural machines. From the beginning it was clear that the fast-prototype would have all the basic features of the final system but it would not be as open, generic and configurable as the final system should be.

The agricultural implement selected for the fast-prototype was a combined seed and fertilizer drill, shown in Figure 1. Tractor equipped with ISOBUS compatible Tractor ECU was also used.

Figure 1. Combined seed and fertilizer driller.

All standard electronics of drill was removed and some additional sensors were installed. For example, the levels in the two containers, for seed and fertilizer and the height of the front leveling board can be measured. The seed and fertilizer feeding rates are controlled corresponding to presicion farming requirements. The positioning of machine was implemented with basic GPS receiver. In ISOBUS architecture, the tractor and each implement has its own ECU. The implement ECU was implemented with a commercial CAN-controller. The controller has plenty of inputs and outputs, both digital and analog. Outputs are 12V/2A, so most of the electrical actuators can be controlled without separate power electronics. The controller is based on 32-bit microcontroller with on-chip CAN-controller. The installed controller is shown in Figure 2.

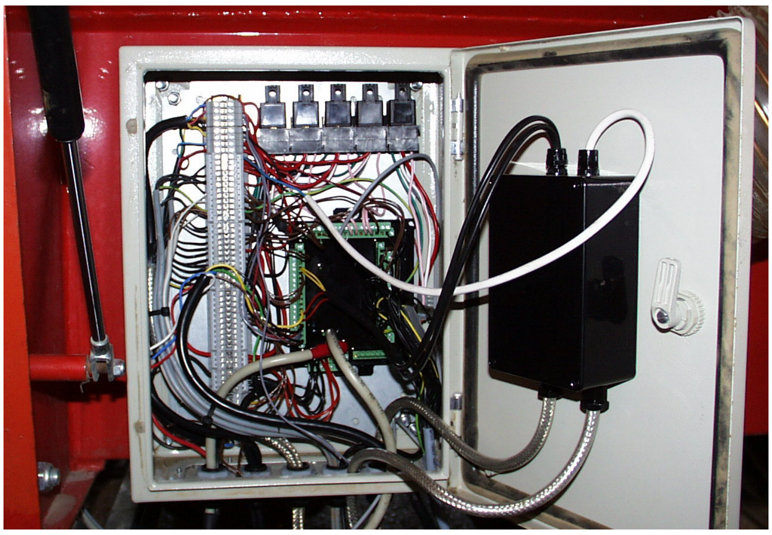

Figure 2. The controller installation.

The software of controller was written in C programming language and it was compiled with gcc in Linux environment due to limitations of commercial controller. Even if the configurability for several implements was dismissed and the program was written in ANSI-C, the program was designed in an object oriented manner. The functionality of the seed drill was divided into components each of which handles a separate action.

The original hydraulic control system of the drill was replaced with a new electro-hydraulic valve block, with which all hydraulic cylinders could be controlled separately.

The architecture of Agrix fast-prototype, shown in Figure 3, was designed according to ISOBUS standard. Three physical ECUs were connected to CAN with ISOBUS upper protocol layers: Tractor ECU, Implement ECU and Terminal which contained the functionalities of both Virtual Terminal and Task Controller. A laptop-PC was also connected to bus, for logging and analyzing purposes. At this phase, any separate ISOBUS VT was not available.

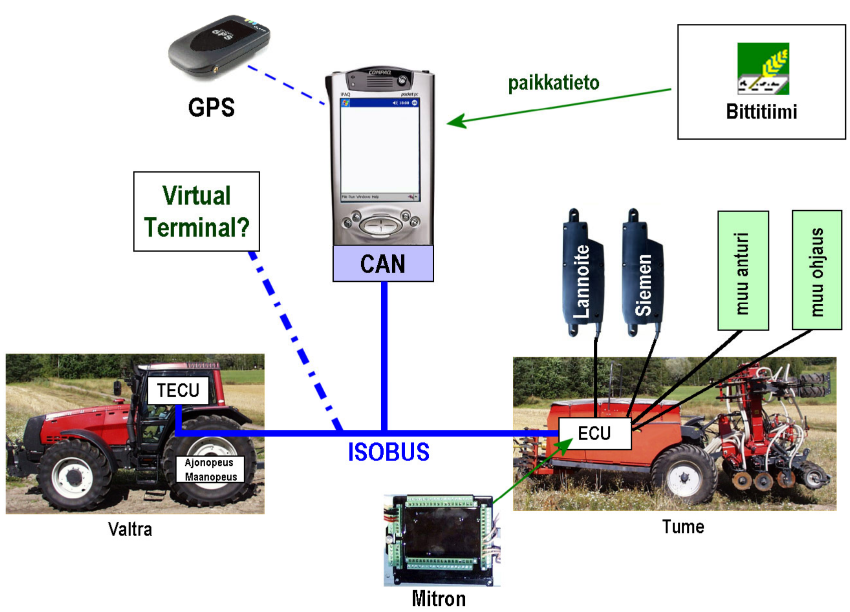

Figure 3. The ISOBUS-based architecture in Agrix fast-proto system.

In industrial automation, standard, inexpensive PCs are used as HMI (Human Machine Interface). Accordingly, it was tested if a standard PDA or handheld (HP iPAQ) could be used as HMI or user terminal for the implement. The connection to ISOBUS was made using commercial CAN-PC

Card. The programs for PDA were made with standard Microsoft development tools for PocketPC 2002 operating system. ISOBUS Virtual Terminal was not implemented fully into PDA, the user interface loading from implement ECU was dismissed. The communication between the implement ECU and PDA was done using ISOBUS messages.

The standard office PDA with cover and external keyboard are in shown in Figure 4. PDA’s user interface is quite small and limited to be used in a moving vehicle. To improve the operability an external control keyboard was connected into the PDA.

Figure 4. The HMI implemented with standard PDA and external keyboard.

Both the Terminal and Task Controller software were running in the PDA. Afterwards it was discovered that some of the processing power problems were due to non-real-time PDA operating system. The CAN-PC Card driver for PocketPC did not support hardware filtering of incoming messages, the processor time of operating system was used much for receiving all CAN-messages. The GPS receiver was connected to the PDA with Bluetooth without major problems.

The HMI software contains eight graphical views for monitoring and operating the machine. In manual mode, all actuators can be controlled one by one: the control functions of the coulter unit attached to the 3-point hitch of the hopper unit, the height control of the leveling board, tramline functions, marker functions, hopper capacity and blower monitoring. The automatic mode contains several sequences: for starting the run, for ending the run, marker control and tramline control. As example two displays are shown here. In the first, Figure 5, the calibration display for the fertilizer feed rate is introduced. The calibration curve of feeder device is tuned in three points. Almost all imaginable operations are implemented, and the number of measurements is the widest reasonable.

The main operation display, illustrated in Figure 6, shows velocity, drilled area, the hopper capacity, marker and tramline situation, state of coulters and navigation buttons.

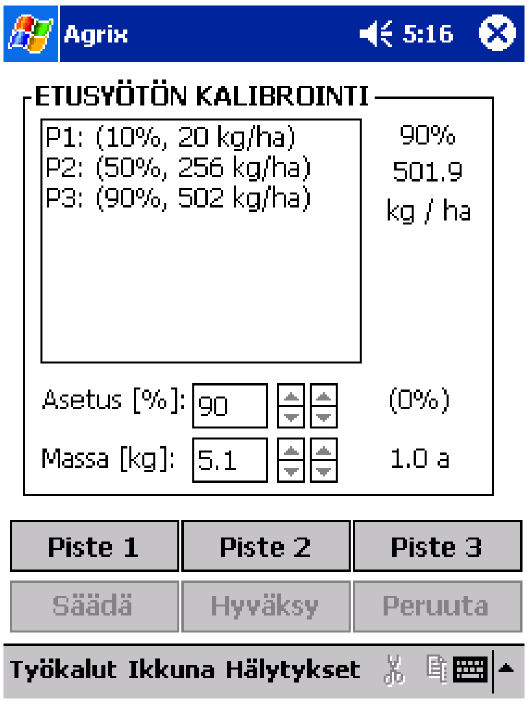

Figure 5. The calibration diplay.

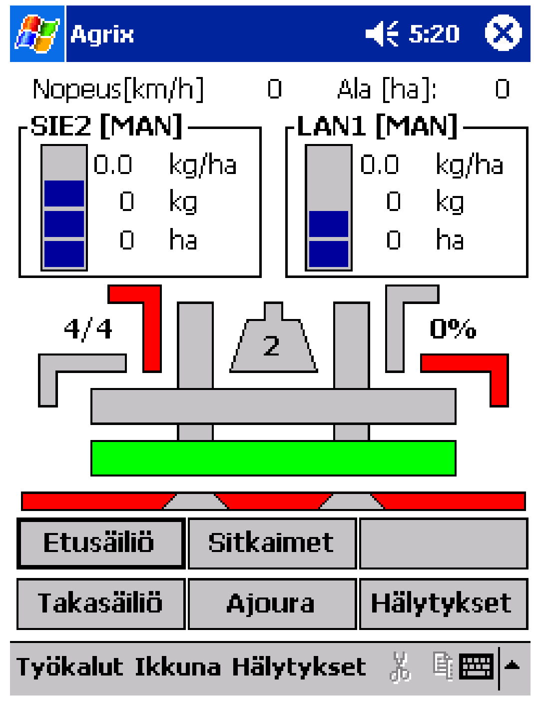

Fig. 6. The main operation display.

Configurability, one of the most important requirements of the project, the was dismissed in the fast-prototype. The demonstrated fast-prototype was not a generic control system, easily configurable with high level tools in connection of different implements. The programs were made using pure C-language. The fast-prototype was operational in autumn 2003 after four months of hard work.

THE FIELD EXPERIMENTS

Agrix fast-prototype system 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. This unit will utilize the Agrix system in studies of operational ergonomics and precision farming itself. These research results will be reported in other publications.

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 is not yet completed. In all communication standards for industrial automation the configuration tools for monitoring and control functions are essential part of the toolset. The ISOBUS does not support configurability at all. The ISOBUS standard contains only communication protocols and format specifications for important variables in agriculture.

In the fast-prototype, the biggest problems occurred with the PDA and CAN-card used with that. The display of the used PDA is quite small for use as HMI in tractor cabin conditions. The inexpensive 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 used CAN-card needs also plenty of processing power in order to handle the whole of bus traffic.

However, the Agrix team learned a lot. Experiences are fully utilized in building the next version, complete July 2004, which will be the platform for further research. Other research areas in Agrix project are positioning and navigation, wireless communication between tractor and implement, optimal planning of driving lines and field traffic.

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