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Aus dem Institut für Technologie und Biosystemtechnik

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Manuskript, zu finden in www.fal.de

Braunschweig
Bundesforschungsanstalt für Landwirtschaft (FAL)
2001

Communication Technology Is the Backbone of Precision Agriculture

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Abstract

Derived from various influences from environment into agriculture and vice versa networking requirements of precision agriculture are explained. At the level of data exchange between agricultural and non agricultural institutions global networks such as the Internet are used and data contents are defined by non agricultural suppliers or customers. At farm level special local agricultural networks defined by DIN 9684 and ISO 11783 are put into action. Main characteristics of these networks are presented.

Keywords

Precision farming, Communication technology, Internet, Agricultural bus system

1 Introduction

Modern agriculture aims for the production of high quality food and raw materials in sufficient quantity for a wide range of customers. Further objectives consist of preservation of resources and protection of the environment. Means to achieve these goals are machines, equipment, and processes with high efficiency and effectiveness. These modern machines and processes are rather complex and consist of various cooperating subsystems. Moreover, agricultural production takes place in an open system which has various relations to its surrounding. This means that state conditions of the surrounding systems as well as the interactions between the agricultural production process and its environment have to be taken into account. Mass or energy flows must therefore be accompanied by information flows. This has led to the introduction of an information-based agriculture, the so-called "precision agriculture".

This kind of agricultural production serves for aiming at the following targets: on one hand one strives for a production process which is in accordance with the demands of plants or animals and realizes this in a site-specific or even single-plant-specific or single-animal-specific way. This results in the necessity to supply data about reference values and controlled variables in great variety, amount, and with short delay time, to transmit these data and process them.

On the other hand, new knowledge, improvements and enhancements should be included in a simple and compatible way into technical equipment and production processes. Furthermore, maintenance and service of modern machines and process equipment should be handled ac-

cording to their real operation times and circumstances. This also requires the sampling, transmission, and processing of data in a compatible way, since the data may be generated, transmitted, and processed in different units. In summary, the compatible data transmission is a necessary condition for achievement of all the aims formulated above. Communication technology thus serves as the backbone of precision agriculture. This paper considers the information flows in different areas of agricultural production as well as their physical and logical realization.

2 Agriculture and its embedding into various influences

Agriculture finds itself in a surrounding with various (mutual) influences and effects, e. g. properties and state of the soil; biological effects and genetic engineering; finances and commerce; demands for quality and quantity of products; research and development; legislation and regulation; climatic conditions; storage, conservation, and further processing; employment, education and health of staff; (agricultural) engineering including mechatronics; information technology; actual temporal conditions.

Fig. 1 schematically shows these influences, where agriculture as main object of this contribution is situated in the center. Arrows mark (main) influences. The surrounding conditions are interdependent, too, which is also indicated. There is no need to point out that, of course, the compilation in fig. 1 is very incomplete with regard to the members of influencing effects as well as the interactions.
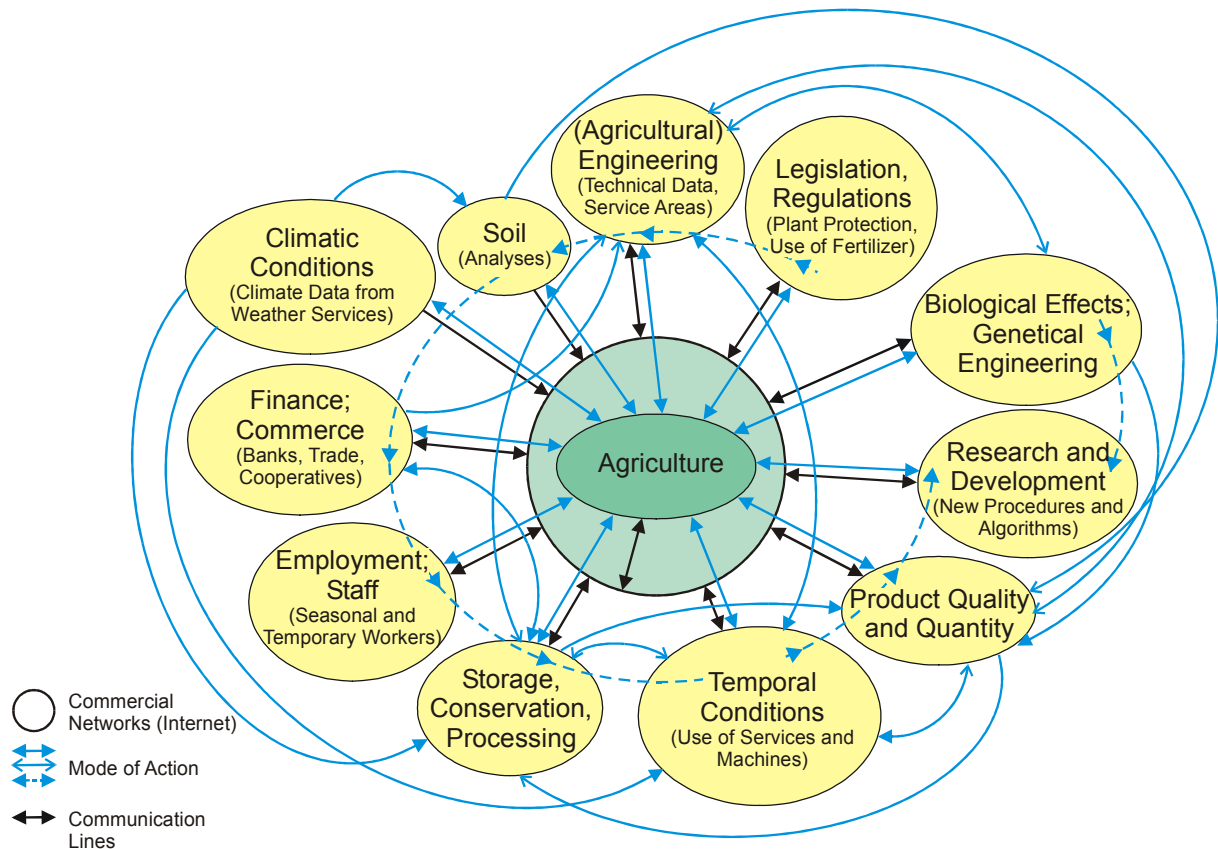
Figure 1: Agriculture, main effects and influences, as well as relevant data communication lines

Agriculture itself consists of a network of various institutions with various mutual interrelations:

- agricultural administration (on a regional, state, federal, EU, and international level)
- agricultural consultants, on various levels
- agricultural professionals' associations
- contractors, machine pools
- farms and cooperatives.

Furthermore, on the farm level with various tasks to be settled, there exist interactions between the economical and technical farm management as well as control mechanisms for plant and animal production processes.

3 Networking requirements of precision agriculture

To meet the demands of precision agriculture, the production must be controlled sufficiently precisely. This leads to an intensive use of measurement and control equipment. These complex electronic systems can only cooperate efficiently if their various components are able to communicate and exchange data automatically. The use of actual information requires an electronic transmission of data. The time scales of the information flows are very different: Consideration of new regulations usually needs response times of weeks or months, while control of application processes in the field goes down to several milliseconds. These different time scales lead to the use of different transmission media.

The automated use of transmitted data is possible only if the structure and definition of data objects is completely known. Here agriculture has to face the situation that another commercial supplier or another financially stronger customer is defining structure and contents of the data. Agriculture thus has to bring its demands into line with established or evolving conventions defined by other disciplines. Only within the core of agricultural activities there is a chance to define standards that meet agriculture-specific demands. Therefore, the data exchange corresponding to fig. 1 will make use of established data networks. Predominantly the Internet with its providers is already used for this purpose, or will be used in future.

Within the center of agricultural activities the situation becomes more specific. But also in this case established communication lines are mainly used; however, the contents and structures of the data may be defined specifically and can follow self-defined standards (agricultural software suppliers, agricultural machinery industry, administration, public information services like the German DAINet, etc.).

4 Networking requirements on farm level

On the farm level, additional new functionalities are expected from the used data communication techniques. Connections between farm and non farm institutions will be done in the same manner as described above. Inside farms, depending on working processes, very different demands arise in terms of amount and time scale of data. At the moment, development and design of farm specific data networks have made greatest progress in the area of plant produc-

tion. Therefore the following explanation concentrates on two networks and their standards [DIN 9684 and ISO 11783], which are planned for mobile agricultural machinery. These networks mainly serve to exchange process data, which are necessary for technical control, information of the operator, and exchange of data with stationary farm computers.

4.1 Network realisations in plant production
In plant production, many production processes are performed by a combination of several working machines or agricultural implements. Modern machines and implements are controlled by electronic control units (ECU). These ECU's are efficiently coupled by a network as shown in fig. 2**.** The LBS [complete name in German: Landwirtschaftliches Bus-System {Agricultural Bus-System}; name of the standard: DIN 9684 (DIN, 1989 – 1998), Landmaschinen und Traktoren – Schnittstellen zur Signalübertragung {DIN 9684, agricultural tractors and machinery – interfaces for signal transfer}] and the Agricultural Bus standardised in ISO 11783 [Tractors, machinery for agriculture and forestry – serial control and communication network] provide open interconnection systems for on board electronic systems, cf. Auernhammer and Frisch (1993) as well as Speckmann and Jahns (1999).

In Germany, respectively in the EU, the realization of this standard has made great progress during the last years. This means that tractors and various implements that fulfil the requirements of the standard are commercially available.

For the development of the LBS, a number of fundamental requirements and pre-conditions had to be considered. The network is anticipated as basis to set up and run distributed process control systems. Examples of such production processes are distribution of fertiliser, application of pesticides and irrigation. For this reason the network has to exchange data between technical components of the agricultural machines with low time delay. In such combinations implements are changed frequently, which causes multiple connections and disconnections at the physical bus line. Therefore a serial bus with simple connectors and cables is regarded as preferable. Changing of implements always alters the network configuration. In order to (i) avoid additional workload for the operator by the necessary network administration and (ii) be independent of a special computer as network administrator, the entire network must be able to monitor, control and reconfigure itself automatically.
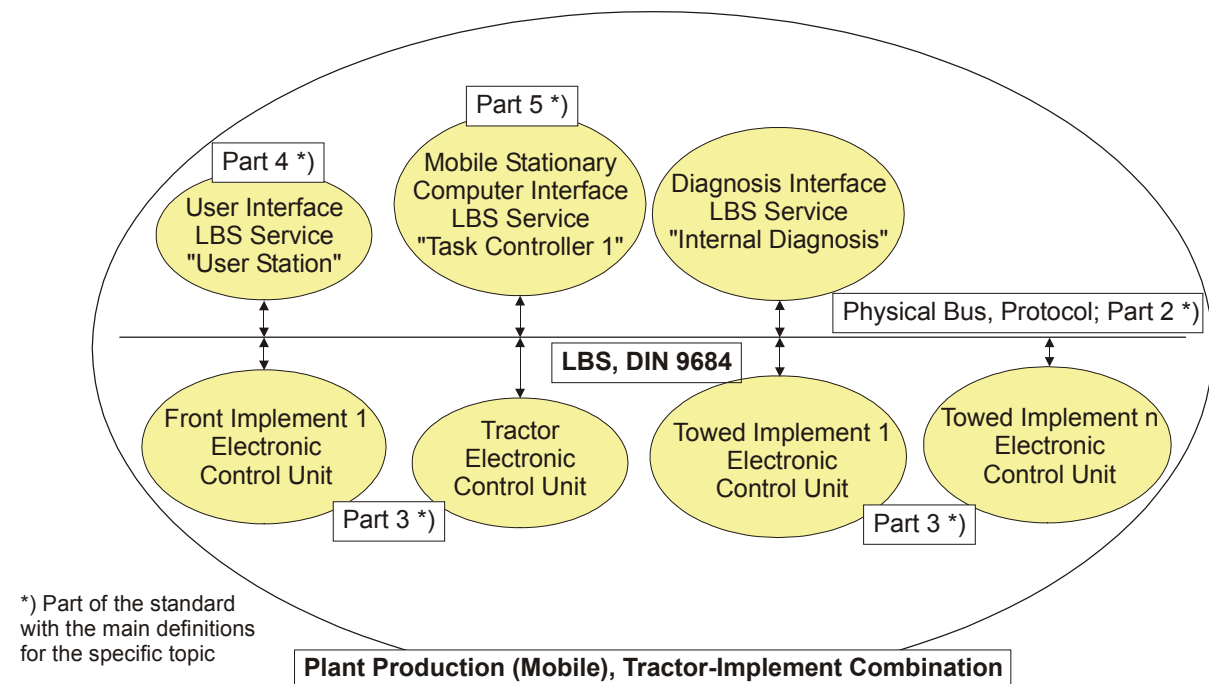
Figure 2: Example of network in accordance with DIN 9684

Additionally, the network must include the possibility for the operator to monitor and control the machine combination. For automated information-based farming, such as precision farming using field operation maps with position-specific set points, data have to be available, which are prepared during production planning on the stationary farm computer. Vice versa, measured values such as soil parameters, yield data, and the like, collected during field operation, have to be transmitted to the farm computer as basis for later production planning. This can only be done by using machine-readable data storage and exchange.

Derived from these pre-conditions the five parts of DIN 9684 were developed. It must be pointed out here that the following text is only a very concentrated summary of the comprehensive standardization documents - DIN 9684 contains more than 160 pages.

Part 1: Point to point connection (not relevant here)

Part 2: Serial data bus - Transport protocol and physical layer
Part 2 of the standard defines the data exchange protocol and the physical bus of the LBS. For the LBS the commercial protocol CAN Version 2.0A, cf. Bosch (1991), was selected. CAN, the Controller Area Network, was designed by the German manufacturer Bosch, and was originally planned for use in automobiles. The following criteria were important for the selection of this commercially available protocol for agricultural communication purposes:
- No special protocol can be created for agricultural purposes
- Functionality of networks in automobiles is similar to that in field machinery
- CAN fully defines bus access and data transport; it also provides transfer safety and error handling

- Integrated circuits with the implemented protocol are available from different manufacturers

- Hardware implementation guarantees high performance and error free use.

CAN is conceptually a network for object-oriented data transfer with random access and collision detection to the bus (CSMA/CD) and with priority control. Object identification and priority control is done by a CAN identifier (11 bit in length, 2048 objects), which must be unique and unambiguous for all nodes. The CAN protocol, especially the use of the CAN identifier (cf. fig. 3), had to be adapted for the application in the LBS because:

- The LBS is an open network for agricultural purposes with frequently changing configurations of very different combinations of field machinery. It needs a much larger number of data objects

- Additional identifier information is to be placed inside the data telegram to label the greater number of data objects

- The CAN identifier must be kept unambiguous. This is realized by including dynamic addresses of the transmitting nodes inside the CAN identifier

- The dynamic addresses are only valid for the actual network configuration and are defined during the initialisation process

- To retain priority control of messages, the CAN identifier is subdivided into eight function groups, which have different priority.

This part of DIN 9684 also defines the physical layer of the network:

- Data will be transmitted on a pair of twisted wires
- The length of the bus line is limited to 40 m
- The transmission rate is 125 kbit/s (approximate 1000 CAN frames/s)
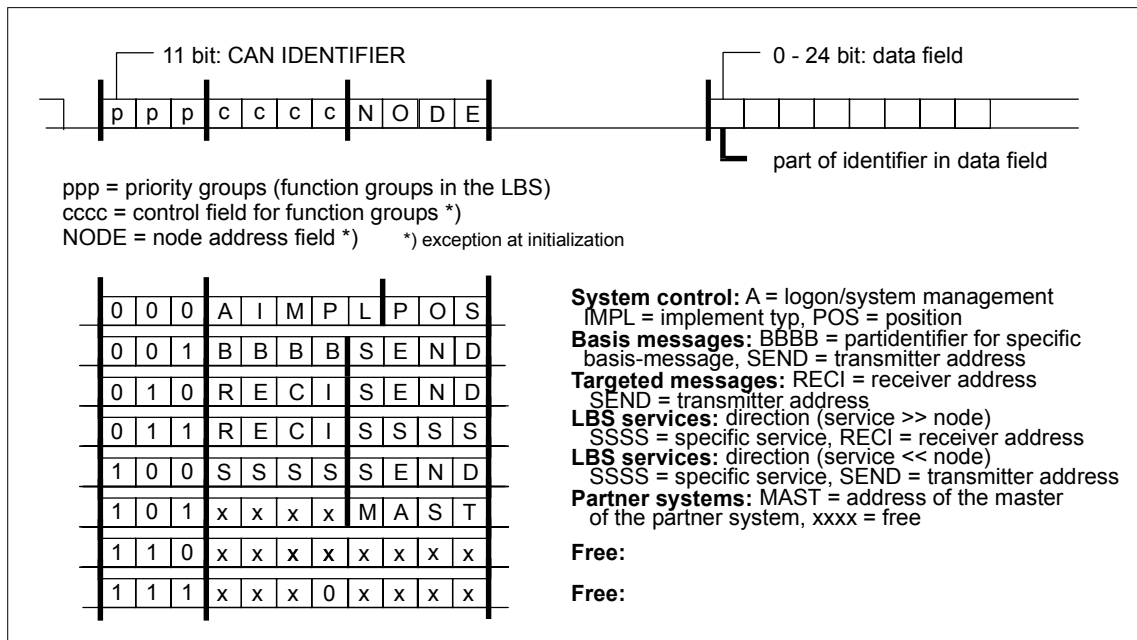- The number of physical nodes is limited to 20.

Figure 3: Function groups of the LBS and modification of the CAN Identifier

Part 3: System functions, identifier - Network management and identifier structure in the LBS

The next part of the standard, Part 3, describes the eight function groups and their basic definitions:

The first function group contains the **"System Functions"** and includes an automatic system initialisation, procedures to claim dynamic addresses, and a system management to control nodes on system level such as monitoring of active participants or release of inactive nodes.

The group **"Basis Messages"** is planned to transmit basis data. These consist of measured data [ground speed, rotation speeds of engine and power take off (PTO), the position of the hitch] as well as time and calendar information. These are provided for all active nodes on the bus via a cyclical transmission in a packed format. Data for process control purposes, the LBS process data, are labelled with a structured data identifier inside the CAN data telegram. Using a structured identifier allows to recognize the meaning and relevance of the data directly by filtering.

The group **"Targeted Messages"** offers another way to transmit process data.

Within the CAN identifiers, the network also offers a slot for OEM defined data exchange. So it is possible to use the protocol and data line for OEM specific purposes with the so-called **"LBS Partner Systems"**. Only a few restraints are prescribed.

Additionally, Part 3 defines the general handling of **"LBS services"**. Because these services are very different in their functionality each one has an own description. Currently two services are defined. Two function groups are necessary for the use of LBS services; one for the data direction from the service to the nodes and one for the opposite direction.

Two further function groups are reserved for future enlargement.

Part 4: User station - LBS service "User Station"

Part 4 of the standard defines the human/machine interface, the LBS service "user station". The user station includes elements for display, data acquisition and direct control of machine functions for all active participants on the bus.

On the operator's side, the user station has several graphic screens. A Data Display presents data relevant to the working process. An Alarm Display informs the operator about alarm situations. A Soft-Key Display shows the actual meaning of soft-keys or menu items for menu control. A Function-Key Display indicates the meaning of function-keys for direct control of machine functions. The operator can allocate these screens to a specific active LBS participant.

On the LBS participant's side, the user station is a virtual unit. The participant generates the screen contents using stored resources or variables. Resources include all instructions to generate display images or dialogue elements. The resources are defined by the participant and loaded into the user station, for example during the initialisation process. Each participant can only use its own resources. An exchange or update of the screen contents is initiated by a small number of LBS data telegrams. The use of stored resources avoids huge bus load during the working process of field machinery.

Part 5: Data exchange with the management information system, LBS service "Task Controller 1"

Part 5 of the standard defines the mobile-stationary interface, the LBS service „Task Controller 1". This service includes three main parts. One part is a non standard communication medium to transport the data from the stationary to the mobile area and in the opposite direction. A second part is a standardized interface between arbitrary management programs inside the stationary farm computer and the communication medium. The third part is a standardized interface between the medium and the ECU in the implement.

The interface inside the farm computer receives or generates transfer files which contain task control data, measurement data, and machine data. Information from the stationary area is processed by the part of the „Task Controller 1", which is placed in the mobile area. It acts as process controller using incoming process control data, machine data, and data about the actual position in the field. The results are sent to the ECUs via the CAN bus according to the definitions of LBS process data. Measured data are collected by the service during the working process. After finishing field work these data are stored on the data transfer medium (chip card, FD, CD, ...).

4.2 Further LBS extension

The standards of the LBS should be adjusted to the expanding demands of agriculture in appropriate periods. Therefore, it must be possible to make adjustments by updates of the relevant software. The LBS already incorporates free definable functions for future tasks. These are special additional LBS services, e.g.:

- A service for a transparent data transmission between stationary computers and the mobile system area. This service allows ECUs and other components to exchange OEM defined data
- A service "positioning and navigation" to measure and provide actual position data of arbitrary implements. A proposal of such a service by Speckmann (2000) shows how an LBS-participant can get data of its own position with multidimensional directions, speeds, and accelerations
- A service for a general system diagnosis, which records and analyses for example network initialisations, bus events before and after system errors, etc.
- Services for machine diagnosis, that provide information about the machinery in a standardized manner.

5 ISO 11783: The international standard for an agricultural bus-system

Agricultural machinery is produced by international industry, so only international standardization is able to guarantee unimpeded data transfer between agricultural systems. Nienhaus (1993) reports that as early as in 1988 at request of Great Britain the establishment of an independent sub-committee for electronics was discussed in Technical Committee 23 (TC 23) of ISO. Subsequently, an independent sub-committee, SC 19, with working group 1, the WG1 Mobile Machinery, was established. This TC23/SC19/WG1 under the actual chairmanship of Canada is responsible for the standardization of the agricultural bus according to ISO 11783. Table 1 shows the state of standardization and the comparable parts of DIN 9684. Whereas basic ideas of ISO 11783 are based on DIN 9684, ISO 11783 is designed for a broader application. Due to the rapid progress in software design and electronics there will be some important differences between the LBS and the ISO definitions. For example, LBS uses the CAN

protocol version 2.0A (11 bit identifier) and ISO the protocol version 2.0B (29 bit identifier) with the higher data transfer rate of 250 kBaud.

Table 1: Comparison of parts of the standards in ISO 11783 and DIN 9684

Number	Title	Status as of June 2000	Equivalence to LBS
ISO 11783	Tractors, Machinery for Agriculture and Forestry – Serial Control and Communication Data Network		DIN 9684 Agricultural Tractors and Machinery – Interfaces for Signal Transfer
ISO 11783, Part 1	General Standard for Agriculture Mobile Data Communications	Working Draft (WD)	DIN 9684, Part 2: Serial Data Bus
ISO 11783, Part 2	Physical Layer	Final Draft International Standard (FDIS)	DIN 9684, Part 2
ISO 11783, Part 3	Data Link Layer	Harmonized with SAE J1939/21	DIN 9684, Part 3: System functions, Identifier
ISO 11783, Part 4	Network Layer for Agriculture Mobile Data Communication	FDIS	DIN 9684, Part 2 and Part 3
ISO 11783, Part 5	Network Management for Agriculture Mobile Data Communication	FDIS	DIN 9684, Part 3
ISO 11783, Part 6	Virtual Terminal	Draft International Standard (DIS)	DIN 9684, Part 4: User Station
ISO 11783, Part 7	Implement Messages Application Layer for Agriculture	DIS	DIN 9684, Part 3
ISO 11783, Part 8	Power Train Application Layer	Harmonized with SAE J1939/71	-
ISO 11783, Part 9	Tractor ECU Network Interconnection Unit	DIS	DIN 9684, Part 3
ISO 11783, Part 10	Task Controller Application Layer for Agriculture	WD	DIN 9684, Part 5: Data Exchange with the Management Information System, Task Controller 1
ISO 11783, Part 11	Mobile Agriculture Data Element Dictionary	WD	-

6 Integration of new fields of operation and new technologies

Network design for animal production

Another field of expansion of local agricultural networks is the area of animal production. Here data communication techniques may be used, which are known from PC technology (such as standard network boards, Ethernet, Novell ,….) to exchange information between the farm computer, control units of technical equipment and components such as self feeders, automatic milking systems, or animal health control. To guarantee compatibility, protocol and data objects should be defined in a standard. Inside of a technical equipment e.g. a feeding system, only the producer is responsible for the way of data exchange between its components. If such a facility is constructed in a modular way with components of different suppliers, physical network, protocol and application should also be fully standardised. The LBS application layer (without restrictions of the CAN protocol) could be the basis for discussion of such an agricultural network for animal production.

New data communication technologies

Modern data exchange techniques via different communication media such as chip card, CD, MD, mobile phone or radio will offer totally new solutions for a lot of problems in all areas of technical equipment. In agriculture, for instance, precautionary service of machinery is meaningful to avoid time consuming repair during harvesting or other critical working conditions. Integration of computer techniques can realise automatic diagnoses. These improvements may be strengthened by remote diagnoses and services based on wireless data telecommunication. Online data exchange between stationary farm computers and mobile field machinery can assist agricultural network services such as the LBS service task controller. Direct access to Internet or other global networks theoretically enables the farmer to plan, decide, and act on the tractor as well as on the farm computer.

Other new technologies
Tremendous progress in technical development will also push forward many areas of agriculture. Here only a little number of examples may be listed. For the area of plant production with mobile machinery, agricultural enterprises are interested in sensor systems which enable to collect on-line (during the working processes) information about positions, soil conditions, parameters of crop, etc. Some new techniques such as GPS based yield data collection already represent state of art. Jahns et al. (2000) state that GPS based calculation of driving direction assisted by image based identification of tramlines will support automatic vehicle guidance. Colour image analysis is an aid for quality measurement, cf. Paul (1996). Rode and Paul (1999) report that spectral analysis of reflected radiation gives information about humidity of soil, humidity of crop, nitrogen content of plants, etc. Standardized transmission of processed measurement data via a network such as LBS makes the data available for many applications.

7 Conclusion

Precision agriculture represents mainly an information based venture. To bring such an enterprise into action, it is necessary to make available information on different levels with variable demands. Therefore data communication in various versions has to be performed. For automatic data processing standardized machine-readable data exchange is mandatory. The actual standards defined in DIN 9684 or ISO 11783 permanently have to be expanded to meet the growing tasks and functions of precision agriculture. For the field of animal production, corresponding standards have to be created, whereby the existing ones may be a guideline.

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