ADVANCED TECHNOLOGIES AND AUTOMATION IN AGRICULTURE

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Contents

Summary

Modern agriculture requires field machinery capable of precise, repeatable operations based on models of systems and processes. In the mechatronic design process, applied to three examples, the efficiency of the design process and the performance of the mechanisms can be improved considerably through concurrent, integrated development. Such advanced systems with modern feedback controllers can generate significant demands for data processing and require substantial communications bandwidth.

Standardized agricultural bus systems form the backbone for the high variability and high-bandwidth data streams.

In the first example, the problem of mechanical grain yield sensors placed on combines, is described. By minimizing the influence of the friction of the grain kernels on the sensor, the total number of calibrations can be limited to once per harvesting season, independent of the condition and type of crop harvested.

Targeted spraying requires an integrated adaptation of field-spraying machines on three levels: the equipping of a spray boom with optical sensors for weed detection, the stabilization of the spray boom to ensure correct location of the spray nozzles on the target after optical detection, and the improvement of the dynamics of the spray equipment hydraulics for fast and correct release of the prescribed dose.

Uniform, accurate has high relevance for crops and the environment. To avoid nitrogen losses to the air (ammonia volatilization), spreading of liquid manure should be carried out very close to the soil (e.g., by trailing feet) and applied to the plants according to actual demand. A control system, based on an extended Kalman filter and Smith predictor, is developed allowing spatially variable dosing for the application flow rate.

Communications networking of production units has become an important feature of agricultural production processes and can be expected to continue to grow. A standardized communication system serves as the backbone for precision agriculture, as demonstrated by the examples in this study.

1. Introduction

Sustainable agriculture aims at the production of high-quality food and raw materials in sufficient quantity for a wide range of consumers. Further objectives are the rational use of natural resources and preservation of the environment. For this reason, modern field machinery and equipment should be able to cope with complex agricultural processes and to execute difficult operations at high efficiencies and without environmental pollution.

To control the performance of these machines, a large amount of information has to be captured by sensors and transmitted to and stored in data logging systems for further processing. Moreover, agricultural production takes place in an open system that has various relations to its surroundings.

Therefore, when these machines and processes are in operation, the state of the surrounding systems, as well as the interactions between the agricultural production process and its environment, must be taken into account. Mass and energy flows must therefore be accompanied by information flows. These facts require the introduction of an information-based agriculture, the so-called "precision agriculture."

"Precision agriculture" means that the production processes must be strictly controlled according to the demands of plants, soil, and environment in a site-specific way. The area of these sites is much smaller than the area of whole fields. For intensive cultures, such as vegetables, a site may even be only one plant. For animal production, this means that each animal is treated individually. Such a site-specific treatment requires the transmission of great amounts of data, such as individual values for references, states, and controlled variables, together with information about weather conditions, date, time, and location.

Additionally, technical equipment and production processes should be upgraded with new knowledge, improvements, and enhancements in a simple and compatible way. Furthermore, maintenance and service of modern machines and process equipment should be handled according to their actual wear, operation times and circumstances.

This necessitates sampling, transmission, and processing of data in a compatible way, since the data may be generated, transmitted, and processed in different units. In summary, 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.

In the following, we give three examples for advanced precision agriculture components: combine harvester, sprayer, and fertilizer spreader. This will be followed by a description of the "backbone" communication, which is organized in the form of a specific agricultural bus system and protocol.

Spatial variability in soil conditions such as texture, structure, soil moisture, and soil fertility give rise to local variations in crop yield. Although the lack of spatial uniformity of the factors that influence the growth of field crops, and hence their productivity, has been known and appreciated since early times, agricultural practice hardly takes into account this spatial variability in traditional arable crop production.

The recent availability of reliable, inexpensive, and precise systems for on-the-go acquisition of the world position of soil tillage tools, machines for crop protection, fertilizers and harvesters during field operation (the Global Positioning System, or GPS, supported by dead reckoning systems), and parallel advances in sensor technology, precision mechanisms, and the information processing power of computers, have led to adoption of the concepts of precision agriculture, site-specific farming, or spatially variable application.

In site-specific agriculture, different field operations are adapted to variations in soil conditions, crop growth stage and yield, the spread of weeds and disease infestation within each individual field. Intra-field variations are captured and the registered data are translated into numerous field maps (e.g., weed, disease, yield, and fertilizer and pesticide application maps) with high resolution.

These maps are the core of site specific crop management that guarantees a more rational use of raw inputs such as seed for sowing, fertilizer, pesticides, and fuel for mobile agricultural machines.

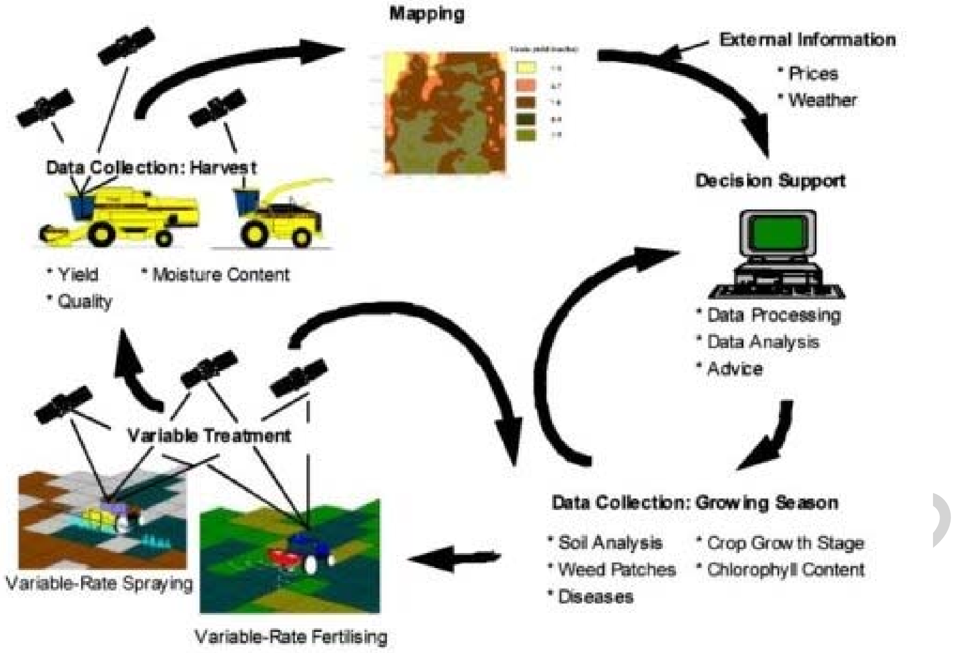

Figure 1: Schematic of a possible future management process for a modern farm

In the near future, a modern farm could be managed as shown schematically in Figure 1. Based on historical data about each field, such as crop rotation, crop yield, soil status, infestation spread, and climatic conditions, decision models determine the essential site-specific soil tillage, pretreatment of the seedbed, and sowing density. During the growth season, the modern farmer decides about site-specific application of fertilizer, supported by crop growth models and field measurements, the most important of which are soil coverage of crops in the early growth stage and evolution of the chlorophyll content of green leaves.

A spraying machine equipped with optical sensors for the detection of diseases and weeds is used for the treatment of local infestations. During harvesting, sensors register the online bulk mass flow of harvested raw produce in the harvesting machine along with product properties that are of important commercial such value as protein and moisture content of cereals and sugar content of sugar beets. These data, related to the captured absolute position of the machine, are mapped in historical records to support site-specific crop management in subsequent growing seasons.

2. Examples of Advanced Precision Agriculture Components: Combine Harvester, Sprayer, Fertilizer Spreader

2.1. Objectives

Site-specific agriculture requires the application of machinery equipped with high-precision devices. Unfortunately, most performance specifications that must be met by machines or machine parts for use in precision agriculture can no longer be met through a traditional sequential design of the mechanism, the controllers, and the information systems. Increasingly, the improvement or adaptation of agricultural machines requires the application of a mechatronic design methodology to meet the stringent performance requirements that are essential for site-specific field operations. In a mechatronic design process, performance of the mechanism can be improved considerably or even optimized through the concurrent and integrated development of precision mechanisms, modern controllers, and advanced information systems.

In this respect, three recently developed mechatronic systems for spatially variable application in arable crop management will be discussed. The first mechatronic design is a high-precision mass flow sensor built into harvesting machines for online measurement of crop yield during harvesting. Next, the adaptation of a spraying machine for selective spraying of those areas with significant infestation is discussed. Finally, a flow rate control system, implemented on a slurry tank spreader for variable-rate application of liquid manure, is discussed.

2.2. Mass Flow Sensor for Combines

2.2.1. Sensor requirements

During the past 15 years, research on yield sensors has focused mainly on the development of reliable grain flow sensors on combine harvesters for measuring the grain yield during harvesting. Although many sensors have been proposed, only a few proved to be suitable for commercial application due to the severe performance criteria imposed on the sensors, the most important of which are:

- The sensor should be able to measure the grain flow with sufficient accuracy such that measurement errors are less than 5%.
- Machine motion and vibration should not disturb the accuracy of the sensor.
- Analysis of the measurement signal before it becomes suitable for deriving yield maps should be simple and straightforward.
- The accuracy of the sensor must remain independent of variations in bulk properties.
- Requirements for recalibration and maintenance of the sensor should be limited.
- The sensor should have an appropriate design for easy integration in combines.

A yield sensor has been developed that amply meets the above-mentioned performance requirements.

2.2.2. Grain yield sensor

The proposed grain flow sensor is mounted at the outlet of the grain elevator, as shown in Figure 2. Figure 3 represents a detailed view of the sensor. The sensor consists of a 90-deg curved plate or chute, supported at the elevator housing by two pendulum rods that can rotate around a pivot point. A beam spring keeps the sensor in its initial position when the machine is at rest. A counterweight is fixed to the opposite tips of both rods such that the pivot point coincides with the center of gravity of the whole assembly so as to render the sensor insensitive to translational vibrations of the combine. In addition, this suspension drastically reduces the influence of driving uphill or downhill on the zero reading of the sensor. Normally, the threshed grain kernels are thrown by the pin parcels into the storage tank. To lead the grain flow smoothly into the sensor, a deflection plate and a rotor are installed at the head of the elevator.

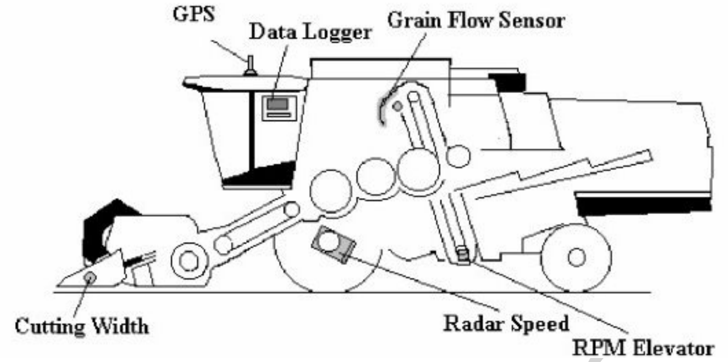

Figure 2: Grain elevator

The grain mass flow entering the sensor exerts a force on the curved plate, causing the assembly to start rotating around its pivot point against the spring force. This final force is the result of the gravity force F_g, the centrifugal force F_{cf}, and the friction force F_f between the grain mass and the curved plate body and thus is a function of the total grain mass m on the plate. Consequently, the registered instantaneous deflection of the beam spring by a linear inductive distance sensor is a measure of the mass flow variations in the curved plate.

Unfortunately, the friction coefficient in the friction force is function of kernel characteristics such as crop type, and moisture content. As a consequence, the sensor must be re-calibrated for different crops and varying harvesting conditions, a very time-consuming and delicate operation. However by properly selecting the projection angle or the direction in which the force on the chute is measured, the effect of the friction coefficient μ can be minimized such that the grain yield sensor is almost independent of the friction parameters of the kernels. After optimization, the influence of friction is less than 0.5 % per 0.1 change of the friction coefficient. For normal grain, the friction coefficient μ varies between 0.1 and 0.7.

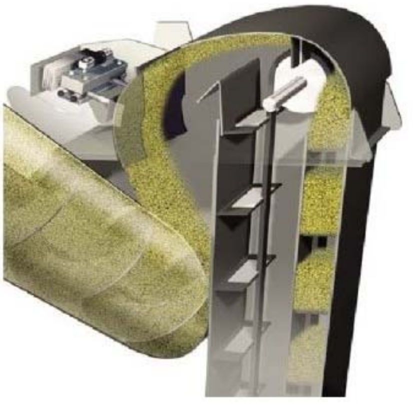

Figure 3: Grain flow sensor

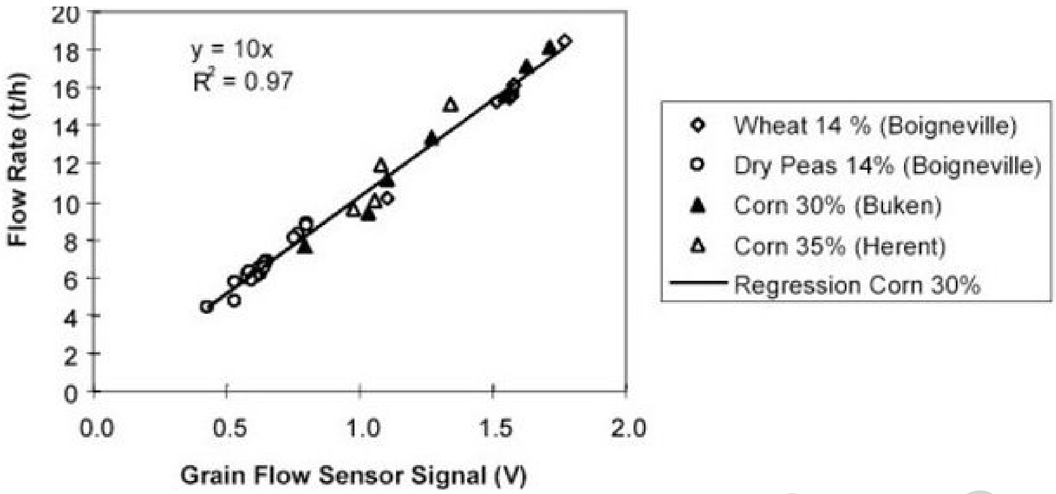

Figure 4: Sensor calibration (the sensor characteristics are independent of crop type and crop condition)

The optimized grain flow sensor has been tested over several years under widely varying harvesting conditions ranging from winter barley with a moisture content of 12% to corn with a moisture content of 40%. The regression lines in Figure 4 show that the sensor is independent of crop type and crop condition. Only the harvesting season influences the slope of the regression line, indicating that the sensor should be calibrated once a year at the start of the harvesting season.

The accuracy of the grain yield sensor was evaluated on harvested areas of various sizes ranging from 120 to 2000 m². The registered yield error is due to inaccuracies in the measurement procedure and sensor inaccuracies. The error in percentage yield increases with decreasing harvested area. For a harvested area of 400 m², matching the grid size of 20 m x 20 m for soil sampling, the maximum error was 5%. For an area of 2000 m², the maximum error decreased to 3%. The error in estimating the yield of a 6-ha field in the Netherlands was less than 1.8%.

2.2.3. Grain yield maps

To transform the mass flow rate data from the yield sensor into a yield map, additional information is collected by the following sensors:

- A capacitive moisture sensor is mounted in the grain elevator to convert the mass flow rate measured at a certain moisture content into a mass flow rate with a standard moisture content (e.g., 14%).
- As a larger cutting width directly influences the mass flow rate in the curved plate, an ultrasonic distance sensor is installed on the header of the combine to measure the cutting width of the knife, which influences the mass.
- A precise Doppler radar sensor to measure the travel speed of the combine, in combination with the ultrasonic sensor outputs, is necessary to relate the actual harvested surface to the measured grain mass flow in the chute.
- To relate the grain yield to the correct location in the field, the absolute position of the combine is determined by a Differential Global Positioning System

(DGPS).

- The transportation time the grain kernels need to reach the yield sensor after the crop is cut by the cutter bar and the smearing effect of the return loop where unthreshed ears are brought back into the threshing process should be compensated in the yield measurements. To this end, an analytical model of the grain flow process has been developed in the New Holland TF78 combine. This model starts by representing the biomass flow above the cutter bar. Subsequently, it describes the transport time of the biomass through the feeding auger and the transport time of the unthreshed kernels in the threshing-sieving mechanism. Once the grain has fallen through the concaves of the threshing drums, the kernel distribution and transport time on the grain pan and the sieves is modeled. A similar model is provided for the return loop. In a final step, the residence time of the kernels in the grain elevator before reaching the yield sensor is modeled.

2.3. Site-Specific Spraying

2.3.1. Chemical Crop Protection

Agricultural production suffers from severe losses due to insects, plant diseases, and weeds. Owing to an exponentially growing world population, crop protection has become one of the most important field operations to increase productivity and crop yield. The most widely used practice in weed control is spraying herbicides uniformly over the agricultural fields at various times during the cultivation cycle of arable crops. To guarantee their effectiveness, overapplication of pesticides is commonly advised; however, excessive use of pesticides raises the danger of toxic residue levels on agricultural products. Because pesticides, and especially herbicides, are a major cost factor in the production of field crops and have been identified as a major contributor to ground water and surface water contamination, their use must be reduced dramatically.

Fortunately, most weed populations develop in patches in the field, with large areas of the field remaining free of weeds or having a very low weed density in the early stage of infestation (Figure 5). As a consequence, herbicides would be used more efficiently if they were applied in the appropriate dose, where they are needed, and not to areas with insignificant weed densities. Thus, weeds have been suggested as the primary target for spatially selective pest control.

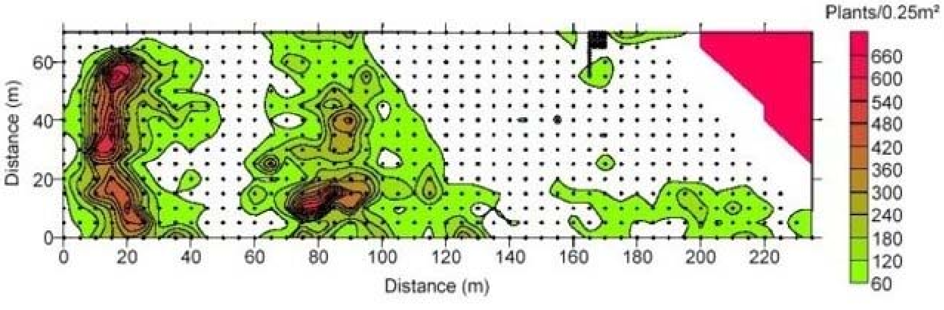

Figure 5: Typical pattern of development of weed populations in the early stage of infestation

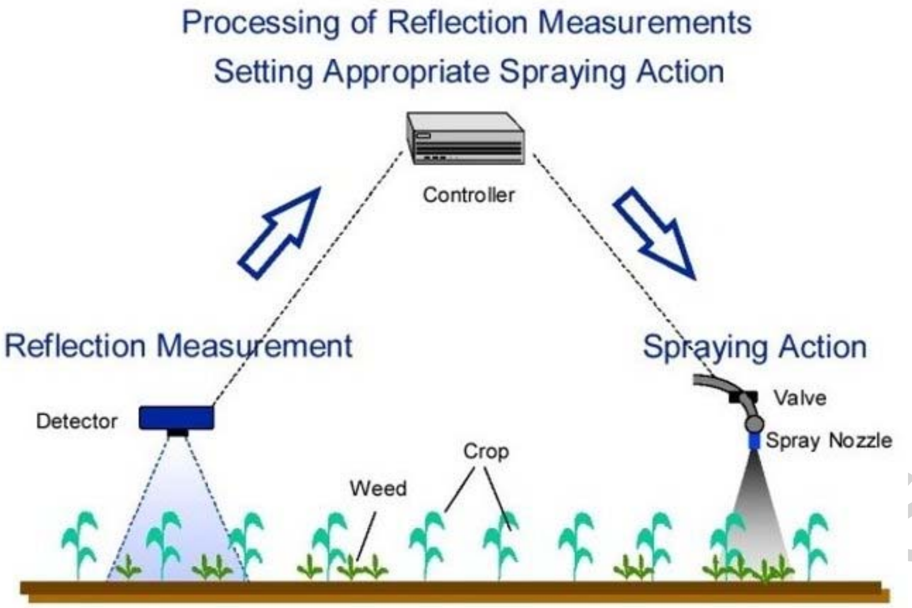

Figure 6: Weed-activated spraying

To set up a local weed treatment, the weed populations must be evaluated in the field. In this respect, two concepts of site-specific weed control have been suggested:

- Weed monitoring is carried out in separate operations prior to the spraying operation ("the mapping concept"). Weed distribution is represented in digitized weed maps, that are later used during spraying operations to activate the spraying system using the board computer of the field sprayers. The instantaneous position of the field vehicle is determined by a GPS receiver mounted on the machine.
- Weed monitoring and spraying are carried out sequentially in the same operation ("the real-time concept"). A real-time weed detection system mounted on the field-spraying machine detects "individual" weeds and transmits that information to a control system that controls the spraying equipment of the vehicle. This is called weed-activated spraying (Figure 6).

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Biographical Sketches

Josse De Baerdemaeker graduated as an agricultural engineer from the Katholieke Universiteit Leuven. In 1975 he obtained an M. Sc and Ph.D. in Agricultural Engineering from Michigan State University and did later post-doctoral research at Cornell University and University of California Davis. He is professor at the Katholieke Universiteit Leuven, Belgium. His teaching and research areas focus on the interaction between physical processes and biological products for the design and control of novel technologies for the cultivation, harvest, handling and storage of crops. He is author or co-author of around 150 journal publications. He is active in international organizations related to engineering and process control for biological systems and served in the period 1996-1998 as President of the European Society of Agricultural Engineers.

Axel Munack 1967-1974: Studied Electrical Engineering at Univ. of Hanover (UH), Germany; 1974: diploma as Dipl.-Ing.; 1974-1980: research assistant, Institute of Automatic Control, UH; 1980:

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Herman Ramon graduated as agricultural engineer from Gent University (RUG. In 1993 he obtained a Ph.D. in Applied Biological Sciences at the K.U.Leuven. He is currently Professor at the Faculty of Agricultural and Applied Biological Sciences of the K.U.Leuven lecturing on agricultural machinery and mechatronic systems for agricultural machinery. Herman Ramon has a strong research interest in precision technologies and advanced mechatronic systems for processes involved in the production chain of food and non-food materials, from the field to the end-user. He is author or co-author of more than 35 international journal papers. Together with Prof. Josse De Baerdemaeker, he is leading a group of about 40 research engineers, of which 7 post doctoral fellows.

Hermann Speckmann received his Dipl.-Ing. degree from the Faculty of Electrical and Mechanical engineering at the Technical University of Braunschweig, Germany, in 1972. Since 1973, he has been a research engineer at the Federal Agricultural Research Centre (FAL) in Braunschweig. His work deals essentially with metrological problems at agricultural production processes as well as with control and automation of agricultural machinery in field and in-house operation. During his research on data communication techniques for mobile machines and tractor-implement combinations he has significantly contributed to the DIN 9684 standard. He has contributed to about 100 publications as an author or co-author.

Jan Anthonis graduated in 1994 as a mechanical engineer specializing in mechatronics from the Katholieke Universiteit Leuven. In 2000 he obtained a Ph. D. degree in Applied Sciences from the K.U.Leuven, Belgium. Currently he is a Postdoctoral Fellow of the Fund of Scientific Research-Flanders (Belgium) and part-time Professor at the Faculty of Agricultural and Applied Biological Sciences of the K.U.Leuven lecturing on mechatronic systems and guiding students in a design seminar for agricultural machinery. His research interests include vibrations on agricultural machinery, hydraulics and advanced controller design in the bio- and agro industry. He is author or co-author of about 20 international journal papers.