Location Based Automation and Information Management in Agriculture - Review and Outlook

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1. Starting at the end - the beginning of Precision Farming

GPS, a position and navigation service with worldwide coverage, became available for civil use in the early 1990s. Agricultural scientists very quickly recognised the potential of this technology for optimising farming practices on a subfield level.

One of the first approaches was to measure grain flow on combine harvesters and log the flow measurements along with GPS position data. Despite poor positioning quality, the resulting yield maps were fit to prove that grain yield may vary substantially within fields.

Good farming practises had always tried to establish a relation between yield and fertiliser input on the field level. With substantial yield variation within the field and a technology to determine the position of spreaders and sprayers, the idea of variable rate application (VRA) was born. VRA involves application maps which locally prescribe varying amounts of fertiliser. The maps are being processed on a terminal which requests the attached devices to vary the amount applied according to the current position.

In the following, several approaches have been made to introduce additional information for creating application maps. Geoferenced soil sampling and soil maps were introduced in order to better understand the local variation of nutrient content and water-holding capacity. The long term aim was to use yield potential maps rather than yield maps and thus overcome the influence of unpredictable parameters such as precipitation and global radiation.

The idea of controlling and steering input on a subfield level as well as tractors and implements has been labelled as Precision Farming or Precision Agriculture. It involves the management of spatial information and location based automation with the aim of optimising yield (agronomic optimisation) and minimising the input of resources (financial optimisation).

In the late 1990s the early starters in the market adopted Variable Rate Technology (VRT). Besides substantial investments, the lack of standards for application maps and communication protocols were the main stop blocks for a broader propagation of VRT in plant production. Also, deriving application maps from yield and soil maps did require a fundamental expertise in data management, plant nutrition and soil science. Due to the above mentioned constraints, it seemed that the adoption of Precision Farming would always be limited to larger farming entities.

About 10 years ago Precision Farming was suffering from the fact that it was an expensive, complicated, science driven technology with low market demand and arguable financial benefits: in case of homogeneous soils and low spatial variation of nutrients the temporal effects (precipitation, sunshine duration) would override the spatial effects.

2. Start over: Guidance, Automatic Steering and Section Control

Precision Farming Technology is composed of different modules. Satellite based position sensors (GPS, GNSS) are a central part and were the initial starting point for the development for Precision Farming.

2.1 Guidance

When it had become clear that other modules like data management and variable rate control on implements involve substantial challenges with respect to communication and agronomy, the GPS industry decided to give way to a simple demand from the market. Almost all tasks in plant production implicitly require to keep vehicles on a track or path. In the late 1990s, the first GPS - based guidance systems have been introduced into the market. They were designed to indicate the deviation from a desired path by means of LED lightbars.

Guidance technology was well accepted and quickly adopted in the market: it was simple to use, fit for multiple purposes and instantaneously helped saving input costs by reducing overlaps and gaps. In opposition to VRT, Guidance technology does not rely on preprocessed application maps and control interfaces to implements.

2.2 Automatic Steering systems

Inevitably, guidance technology evolved towards automatic steering. The first automatic steering systems were introduced by companies already involved in machine control approximately 10 years ago. Due to the need to interface with hydraulic or electronic steering systems of tractors automatic steering systems were by far more complicated to adopt than manual guidance systems. The systems were expensive and needed proper design and setup for meeting safety regulations.

Single frequency DGPS receivers had been considered to be accurate enough for yield mapping, soil sampling, VRT and guidance applications. Automatic Steering systems introduced dual frequency RTK-GPS-technology into precision farming. It was foreseen that single frequency GPS would not satisfy the demand when steering a vehicle accounting for position, roll, pitch and yaw.

Over the last 5 years, the market for automatic steering systems has substantially grown. The producers were able to adopt quickly to different tractor platforms developing generic hydraulic interfaces. The number of suppliers has grown and the tractor manufacturers have started to offer integrated ex factory steering solutions. GPS-based steering assistance systems actuating the steering wheel rather than interfacing with the hydraulics have helped to reduce the costs for platform kits and cut down the cost for installation and setup in the field.

2.3 Autonomous Vehicles

GPS-based guidance and automatic steering systems have never aimed at replacing the operator. They are designed to relieve the driver from steering and allow for more intensively monitoring the tractor and the attached implement. They are not yet designed to operate a tractor autonomously.

Already in 1999, Munich based Geo Tec had presented their Agro Nav system at the Agritechnica show in Hannover. Agro Nav was a self contained system for pre-planning tracks, vehicle speeds and implement actuation on a PC. A complex control system on the tractor was designed to accomplish the mission plan autonomously in the field. The system failed in the market due to its high price and the complexity of its planning system.

Some recent research projects focus on the development of autonomous and semi-autonomous tractors. Weltzien [8] has presented a system which allows for automatically positioning trailers beside forage harvesters for optimising the process of overloading. The Electronic Tow Bar [3] uses GPS-technology to make an unmanned tractor follow a manned tractor with a defined offset and distance. Ruckelshausen [7] is extensively working on developing an autonomous robot for individual plant crop scouting.

2.4 Automatic Boom Section Control and Row Shutoff

With guidance and automatic steering systems on tractors, GPS-technology has been available for further use. The demand from the market and the motivation of suppliers to develop add-on technology resulted in the development of automatic boom section control systems. Rather than controlling the application rate, boom section control systems automatically switch sections off when covering areas that have already been applied.

Again, boom section control was quickly accepted and easy to introduce as it does not rely on any preconditions like application maps. Alike VRT, boom section control systems depend on an interface with the implement. The lack of communication standards still substantially slows the adoption of boom section control systems on sprayers and spreaders.

3. Agronomical Effects beyond VRT: Implement Steering and Control

The capability to determine a position with an accuracy of 2 cm with RTK-GNSS may also be adopted for steering and controlling implements. Implement steering and control does not necessarily rely on the variation of rate, but still may help to save costs and improve the quality of the product grown in the field. The benefit of the applications below is again not dependant on heterogenous soils or climatical effects.

3.1 Implement Steering

Towed and even hitched implements tend to drift sidewards. This is especially the case in slopy terrain but may also be induced by changing soil texture. Implements will also not follow the track of the tractors when driving curves.

In some applications it is critical to maintain an accurate spacing between plant rows. Soil compaction has a negative effect on the growth of potatoes. It is therefore highly desirable not to compact the cultivated soil with the tractor wheels in the rows when planting. It is also crucial to place the potatoes in the middle of the dam when planting. Potaoes planted near the edge of the dam are likely to be damaged during subsequent treatments and may lead to exposure of the potatoe plants to sunlight.

Automatic implement steering systems help to keep implements on track while planting. Less soil compaction in the row results in higher yields. The potatoes being planted in the middle of the dam can reduce the amount of green potatoes substantially thus improving quality and reducing the expenses for good seperation on the harvester or in the plant.

Several suppliers of automatic steering systems also offer steering systems for implements. In most cases implement steering is an optional extension and requires a steering system on the tractor. Implement steering systems range from coulter to tongue steering systems. Some side shift systems can even steer the implement without steering the tractor itself and operate completly independent.

3.2 Strip Tillage

StripTillage farming aims at reducing the cultivation and the application of nutrients to strips - the rows where plants are growing. The major advantage of Strip Tillage is a substantial reduction of fuel costs with less area being cultivated. It also expected that not culivating the interrow space will increase soil fertility and reduce erosion. Strip Tillage also aims at placing the fertilizer in the row next to the plant roots rather than spreading it equally in the row and between the rows.

Strip Tillage requires equal row spacing, also beetween tracks. The ability to revisit the strips with a very high accuracy is a necessity. The application of GNSS-based implement steering is therefore a basic requirement for the implementation of Strip Tillage Farming.

3.3 Automatic Steering and Triggering of Seeders in Parcel Plot Trials

Parcel plot trials help breeders to judge the relative excellence of different plant breeds under *ceteris paribus* conditions. Parcel plot trials are a complex of rectangular structures which are created by seeding in the open environment. Marking the egdes and pathways of parcel plot trials with convential methods is very time consuming and elaborate. It often delimits the number of parcels that can be created during one season and therefore indirectly limits the breeding success.

GNSS steering and control systems have helped to automatically steer tractors while sowing parcel plot trials and the maintenance of pathways between the parcels. Some systems are even designed to automatically trigger the seeder when it enters a new parcel and thus induce the seeding of a new breed.

3.4 Grid Seeding

Mechanical hoeing is superior to chemical plant protection when it comes to improving soil fertility, water conservation and the protection of environment and consumers [7]. One of the major drawbacks of mechanical hoeing is the control of weeds growing in the interrow space. The ability to create a rectangular grid of plants in the field would allow for hoeing in and crossways to the seeding direction [1,7].

Kverneland has recently presented a system called Geoseed. It is based on GNSS-systems and allows to create a rectangular grid of maize and sugar beet plants in the field. However, the system has not yet been introduced in the market.

Grid seeding and hoeing both in seeding direction and perpendicular to it is another application solely based on positioning and controlling an implement. It is promising with respect to raising yield, improving soil fertility and protecting the environment without varying application according to predefined maps.

4. Challenges: Standards, Data and Information Management

Most of the above mentioned applications for GNSS in agriculture does not involve any or hardly any exchange of data between the steering and control systems on the one hand and tractors, implements and farm software on the other hand. The ability to operate beyond the need for interfaces have made the systems universal and independant of brands and models.

Further extending the benefit of GNSS will rely on further integrating steering and control systems with tractors, implements and farm software.

4.1 Standards: ISO 11783

The implementation of ISO 11783 is the key to further develop location based autmation and data management in agriculture. It provides a universal interface between control systems, tractors and implements with respect to steering, boom section control, capturing process data and variable rate technology. The standard makes all the above mentioned tools for location based automation independant of tractor platforms and implements alike the existing standards for three point hitches making the mechanical link between tractors and implements independant of brands and models [2].

A major drawback for further disseminating automatic steering systems are the costs for retrofitting sensors and actors on tractors. Most platforms require an individual adaption of the hydraulic steering system and the steered axle to fit electro-hydraulic valves and steering angle sensors. The ISO 11783 standard provides an interface to the steering systems of tractors. Besides installing sensors and display units automatic steering systems using the ISO interface for steering only require a connection to the CAN Bus. The installation is thus less time consuming and almost universally applicable independant of the tractor model.

The same priciple applies to boom section control systems and variable rate controllers. Rather than implementing propietary protocols for controlling boom sections or site specific rates the ISO 11783 standard suggests universal messaging for controlling implements independant of brand and model. The standard facilitates an easy and universal installation and calibration thus cutting down the net costs to the end user. ISO 11783 task controllers may also be moved from one machine to another and can serve multiple purposes whereas propietary controllers can only communicate with specific implements. Multiple use again helps to reduce costs for precision farming technology.

4.2 Process Data

GNSS sensors deliver accurate information on position and time. When GNSS sensors are on a tractor to help the driver with guidance, position and time measurements may also be logged for the documentation of tasks. This is especially helpful when positions are stored along with additional information such as the type of attached implement, driver, fuel consumption and the status of the three point hitch. When the field boundaries are known to a process data collection system the data collected may automatically be assigned to fields.

Collecting and analysing process data helps to understand input and return on a subfield level even when fields are farmed uniformely not applying variable rate technology. Process data analysis also allows to understand the effect of the distance between farm and field when the time for travelling to and from the field is determined with GNSS data and assigned to the correspondent tasks. Contractors can thus individually determine cost and return of tasks performed for certain clients or in selected regions and thus optimize task disposition in the following years.

Rothmund [5] has presented a farm management system called transborder farming. It allows for farming several adjacent fields as one field while assigning all tasks and the related costs to the underlying field borders and their owners. The system also automatically refers yield data (=income) collected on combine harvesters to the subfields and their owners.

Process data collection is a byproduct of steering and boom section control systems. Analysing process data can help to determine sinks in plant production and are fit to streamline the production process without locally varying input. One of the main reasons for the fact that process data collection has not been widely established is again the lack of standards for transferring process data from the machine into the office. Also, the percentage of tractors featuring ISO Bus data such as fuel consumption and implement status is today by far too low to make universal systems for data collection financially viable.

4.3 Data and Information

One of the most challenging tasks for location based management is the conversion of data into information. Todays technology allows for storing large amounts of sensor and process data in a very short time. The ability of location based management systems to support farm managers in decision making relies in their ability to reduce the data to relevant information.

After twenty years of yield mapping the generation of meaningful yield maps from yield data applying Kriging or Inverse Distance interpolation methods still relies on profound knowledge. Deducing yield potential maps from yield and soil maps requires expert software and thorough training.

Also, the processing of large amounts of task data has not yet been properly adressed. Farm Managers will have to be supplied with simple analysis tools that allow for supervising the performance of preplanned tasks and reviewing the economical feasability of tasks performed in the past.

4.4 Precision Agronomy: Microclimate and growth models

The agronomical aspect of precision farming is by far more complex than steering tractors or implements. It has to take into account the spatial and temporal variablity of soil and climate. Agronomical precision farming relies even more on the above mentioned decision support systems for rendering information or suggested prescription rates from historical data (e.g. yield maps) and sensor data collected online or offline (e.g. N-sensor, airborne imagery).

Recent research projects have shown that online sensors, terrain, growth and climate models provide a large potential for optimizing plant production. The research project geostep [4] has presented an integrated approach to combine terrain models, global climate models, data from local weather stations, satellite imagery, soil maps, historic yield maps and plant growth models into an advisory system for fertilizing applications.

However, the adoption of agronomical precision farming today is still very time consuming and relies on well trained farm managers with a strong background in IT and information management or external input from advisory services and thus is not fit for average farming operations in central Europe.

5. Summary

The development of Location Based Management in Agriculture (precision farming) started off with yield data collection about 20 years ago. Yield maps were to determine low and high yielding zones within fields and to serve as a basis for site specific management. Agronomical precision farming and the concept of variable rate technology soon revealed weaknesses due to lacking standards for controlling fertilizer spreaders and other implements. It also turned out that the conversion of soil and yield maps into yield potential maps is highly dependant on expert knowledge and the adaptation to local climate and soil conditions.

GNSS based steering technology and boom section control systems were successfully introduced into the market during the last ten years. In opposition to site specific management the technical approach to Precision Farming does not rely on agronomical information. It is therefore easier to adopt and helps saving input costs immediately.

The collection of process data during all tasks performed in plant production represents another approach to economical optimization on a subfield level which again does not rely on spatially varying factors such as soil or climate. Both, further dissemination of steering and control systems on tractors and implements as well as the economical analysis of plant production on a subfield level based on process data is limited by the adaptation of universal standards such as ISO 11783.

Further developing concepts for data and information management is the basis for adopting agronomical precision farming and process data analysis on a wider scale. Farm Managers will need systems that provide information for decision making rather than only storing data.

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