# Contributions of Dutch Agricultural Engineering Research to Precision Agriculture [1]

## *Beiträge der agrartechnischen Forschung in den Niederlanden zur teilflächenspezifischen Bewirtschaftung*

Bert Speelman

Landbouwuniversiteit Wageningen, Niederlande

**Abstract:** This article resumes contributions of the Dutch agricultural engineering research to the development of precision agriculture. Dead reckoning systems are discussed for the enhancement of positioning accuracy. As a fundamental basic for handling georeferred data in agriculture new information models were developed. The precision of site specific fertilizer applications was examined by modelling of spread patterns. To allow an automatic mass flow calibration for fertilizer spreaders a dynamic weighing system is described.

***Kurzfassung:** Einige in den Niederlanden durchgeführten Forschungsarbeiten zur teilflächenspezifischen Bewirtschaftung werden vorgestellt. Mit Hilfe der im Beitrag diskutierten kombinierten Systeme zur Ortung können die Genauigkeit und der Anwendungsbereich des Global Positioning Systems (GPS) vergrößert werden. Als Basis für die Behandlung von georeferierten Daten bei teilflächenspezifischen Feldoperationen wurden neue informationstechnische Modelle entwickelt. Beim Ausbrigen von Düngemitteln läßt sich der Effekt über unterschiedliche Verteilungsmuster abschätzen. Untersuchunsgergebnisse zum dynamischen Wägen gestatten es, den Massestrom automatisch einzustellen.*

### Introduction

Precision agriculture can be defined as agriculture which considers the spatial variability within fields. It aims to provide for each different unit or plot an optimal treatment in space and time by using advanced and integrated technological system components. The general opinion is that this type of farming will benefit economic and environmental aspects of agriculture (Robert et al, 1993). Precision agriculture highly depends on the use of electronics and computers. The use of computers and management information systems makes it possible to store data over many years and to use them for management purposes. The specifications for agricultural practice can be made location specific and implemented during field work (Goense et al, 1996). Advanced sensors like GPS receivers, yield sensors and ground bound remote sensing devices are playing an important role (Goense, 1996). Practical applications are already found in the flow meters of combine harvesters, vision systems for the determination of weeds and sensors for the determination of soil properties. The Farm Technology Group of the Department of Agricultural Engineering and Physics of the Wageningen Agricultural University has adopted precision agriculture in its research programme since 1993. Following items are currently under research:

a. development of information models for the description of systems for spatially variable field operations.
b. data interchange between management computers and mobile computers.
c. development of a calculation method for the estimation of the benefits of site specific fertilizer application.
d. enhancement of a global positioning system with dead reckoning and
e. development of a dynamic weighing system for a more accurate fertilizer application.

In this contribution we will shortly discuss some of these items.

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## 1 Information models for the description of systems for spatially variable field operations

In the framework of an Esprit III project on "Computer Integrated Agriculture" a generic information model for agriculture has been developed. Part of it was a submodel that dealt with geographically related information (Goense et al., 1996). The aim of this submodel was to link different geographical objects (buildings, roads, field, part-fields etc.) to data used or collected during field operations like ploughing, seeding, weed control, combine harvesting etc. However, operations on a farm in general are not restricted to field operations but they also include work in or on buildings, ditches etc. Besides, they are not exclusively executed by the farmer or his personnel but they may also be executed by a contractor. A contractor does not only work for the farmer but he also may do road work like mowing, or cleaning of ditches. All operations have in common that they are related to topographical objects and so the model must be able to cover all these different objects. One requirement in data modelling is a clear and unambiguous definition of entity types and attributes. The entity type field is much less clear than a road or building and may differ from country to country or from region to region and so a clear definition was made (see Goense et al., 1996). For spatially variable field operations, the details of an operation depend on the position in the field and thus on geographical information. In our work four different types of geographical data representation were used. (1) lane table; (2) pattern table; (3) raster table; and (4) polygon table (see **fig. 1**).

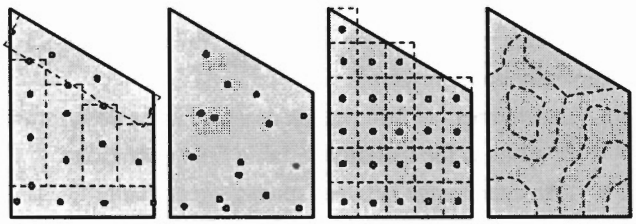


Fig. 1: Four methods to locate site-specific data (According to Goense et al, 1996)
*Bild 1: Vier Methoden der Zuordnung teilflächenspezifischer Daten*

They are able to handle point-related or area data. Pro's and con's are described by Auernhammer and Muhr (1991), Webster (1985) and Van der Knaap and Van der Meer (1993). Data for farm operations may be distinguished, because of the different characteristics into:

a) Data directly related to operations: product and/or produce dependent or independent specifications. The first group includes eg. fertilizers or crop protection chemicals; the second ones include machine settings like seeding or ploughing depth, or disc speed of a fertilizer spreader.
b) Data related to a crop production unit e.g. height or colour of a crop, moisture content.
c) Data collected during the execution of an operation e.g. light reflection of a crop in certain wave bands, indicating crop development.

The type of data discussed before can be determined for a field operation as a whole (average driving speed, fuel consumption, applied amount of fertilizer) or for a crop production unit as a whole (average crop height). Given the differences within a crop production unit or a part-field it is essential to relate data not only to an operation or crop production unit but also to the locations. Therefore, a link between data types and locations is required.

Merging of the components results in Entity Relationship Diagrams. Examples of ERDS including geographical information and specification of data are extensively presented by Goense et al., 1996. From their work it can be concluded that systems for handling of data for spatially variable field operations have to be based on a generic model. Such a model has to be descriptive. The information model is needed to establish a common level of understanding which is necessary for successful application. Such a system must also be able to handle different types of presentation of geographical related data, and different types of data itself. Data exchange between systems must be possible.

## 2 Precision of site specific fertilizer application

In precision agriculture, apart from the evenness of distribution, the application of the required variable rates for specific locations in the field becomes important. In this section we will present some results of a calculation method developed by Goense (1996) for estimation of the effect of different application techniques of fertilizer in site specific agriculture. The accuracy has been expressed in terms of deviations between required and applied rate per square meter.

Following aspects were considered:

- effect of fertilizer spread pattern (working width, size and shape)
- resolution of the required application rate
- accuracy of the positioning system.

The spread patterns had the following characteristics:

1. a theoretical spread pattern with a square pyramid shaped distribution area.
2. a theoretical spread pattern with a square flat shaped distribution area.
3. spread patterns of sections of a pneumatic spreader with a rectangular roof shaped distribution area.
4. the spread pattern of a reciprocating spout broadcaster with a distribution area of 29 m wide and 8 m deep. The effective working width was 12 m.
5. the spread pattern of a two disc centrifugal broadcaster with a distribution area of 41 m wide and 25 m deep. Effective working width was 18 m.

The spread patterns are two dimensionally described by relative distribution patterns of 1.0 * 1.0 m. Coefficients of variation of combined transversal distribution are 0.0% for the theoretical distribution patterns and 1.6% and 3.3% for the reciprocating spout broadcaster and the centrifugal spreader respectively at the set value of the effective working width. These coefficients of variation are low because the main interest is focussed on the pattern shape and dimension in relation to variation in positioning accuracies on the distribution patterns. Based on earlier work of Van Bergeijk (1996) variations in position accuracy of a DGPS code receiver, standard errors of 0.0, 0.5, 1.0 and 2.0 m were considered.

The characteristics of the field variability is expressed by an exponential variogram model which gives the relation between the so called semi-variance and the lag distance. An important parameter in such a variogram is the range which can be described as the mutual distance at which the maximum semi-variance is reached. In this study different levels for the range are used to express the variability of the field. In an experimental field in the Netherlands the ranges for the N-content were in the order of 150-250m. With a computer program the variance between the required rate and applied rate for discrete areas of location specific fertilizer application was calculated based on the spread patterns mentioned before and for resolutions of the required application rates of 1, 3, 6, 12 and 24 m. Standard deviations of positioning were set at 0.1, 0.5, 1.0 and 2.0 m and the range values were 32, 64, 128 and 256 m. Following results were obtained with respect to effects of shape and the effective working width of the spreading pattern.

When positioning is nearly perfect with a standard deviation of 0.1 m and when the required N-application rates are given with the highest possible resolution of 1.0 m no variance with a spread pattern of 1.0 * 1.0 m is found. Increase of the effective working width gives an increase of variance between the required and applied rates, depending on the field variability as expressed by the range. The higher the range, the lower the variance at given working widths. Pyramid shaped spread patterns give a lower variance than flat ones. This can be explained by the fact that the highest fraction is applicated on the location at the centre point of gravity of the pattern. The reciprocating spout broadcaster and to a certain extend the centrifugal spreader have their highest fractions concentrated near the centre point of gravity. These concentrations are even more pronounced than for the theoretical pyramid shape, which explains why the variance is lower. The theoretical spread patterns for the pneumatic spreader show for larger working widths of 12 and 24 m a higher variance than the other types, which can be explained by the high fractions at the outer sides of the rectangular pattern. Positioning accuracy with standard deviations of 0.1 - 2.0 m does not affect variance when the effective working width of the controlled sections is greater than 12m. The effect of positioning accuracy is lower for working widths of 3 m and smaller. When positioning equipment with a standard deviation of 1-2 m is used with high resolutions of required application rates, the optimum working width is 2 or 3 m, depending on the field variability.

The effects of the resolution of the required rates can be demonstrated from the pyramid shaped patterns combined with nearly perfect positionings. High resolutions of the application rate set points result in lower variance between required and applied rates over all ranges of working widths. However the positive effects are more pronounced at smaller working widths. When less accurate positioning equipment is used in combination with higher resolutions a small increase of the optimum effective working width was found.

## 3 Enhancement of global positioning systems with dead reckoning

As stated earlier, the use of positioning systems on agricultural machinery is an essential part in site specific crop management. Positioning systems based on satellite signals offer good possibilities for machinery operations under field conditions (Stafford and Ambler, 1994). A major drawback of such systems is the reliability. When for instance obstacles like trees or buildings block the satellite signals erratic results occur. Accuracy can be improved by adding a dead reckoning method, which works without the use of external beacons. In this section results of a global positioning system combined with a dead reckoning method based on wheel velocity, radar velocity and compass heading, with respect to positioning accuracy are presented. In **fig. 2** the components of such a positioning system are shown.

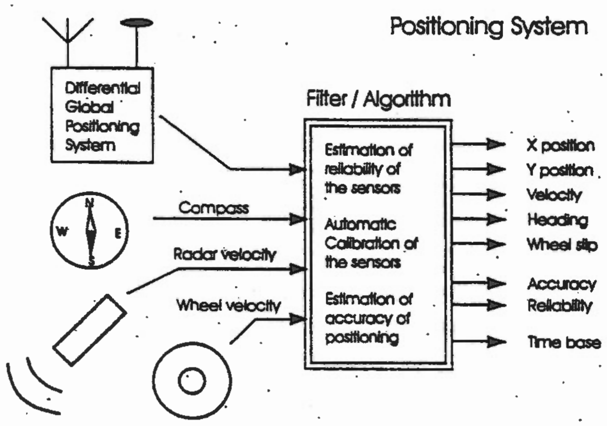


Fig. 2: Components of a positioning system
(According to Van Bergeijk et al, 1996)
*Bild 2: Komponenten des Ortungssystems*

The system has to integrate these different position, velocity and heading measurements by a filter algorithm. The main filter was based on the extended Kalman filter algorithm. The individual sensors were analysed by examination of the logged data from several experiments including different tractors and different field and road condition (Van Bergeijk, 1966). Three Kalman filter designs were evaluated by implementing real time versions on the personal computer to operate on a tractor. The reference points at ten locations aside an prescribed track were marked by a pole and digitized in the data logfiles through a light bridge. The filter and average performance of the three validation runs are given in **table 1**.
The errors of the individual sensors are in general larger than the filter output. Only the heading output error of filter C is slightly worse than the original compass error. Differences between filter A and B are small. Filter C position error improvements are at the expense of slightly larger velocity and heading errors. To test the behaviour of that filter under poor satellite "visibility" conditions, a track on a farm yard, along buildings and a lane of trees, has been chosen. In **fig. 3** the driving direction is from south to northwest (X coordinates are west to east and Y coordinates are south to north).

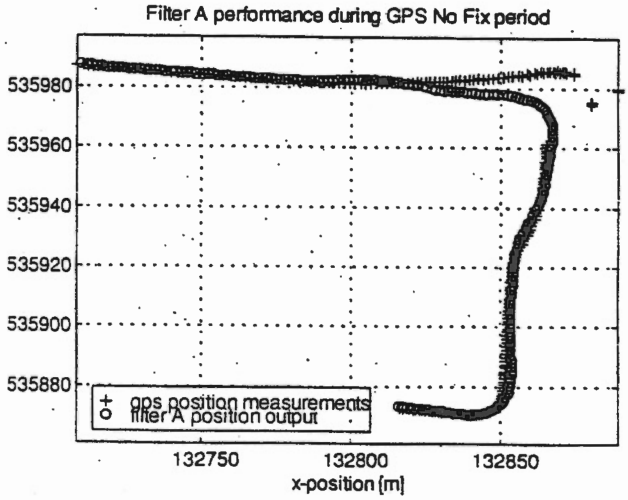


Fig. 3: Filter A performance on a track across a farm yard
(According to Van Bergeijk et al, 1996)
*Bild 3: Ergebnisse mit Filter A bei einer Fahrt über den Farm-Hof*

At the northeast corner of the yard the GPS looses satellite fix and jumps to positions 20-39 m from the real position. According to the emphasis on dead reckoning, the path of the tractor shows the turn from the yard onto the road while the GPS needs about 80 m during 10 s to recover from the satellite loss. From the experiments it was concluded that the position output improved up to 43% when using a nine state Kalman filter integrating dead reckoning with GPS.

Table 1: Filter performances compared to sensor performances (According to Van Bergeijk et al, 1996)
*Tabelle 1: Vergleich der Filterdaten mit den Sensordaten*

| | Position error [m] | | Velocity error[m/s] | | Heading error [rad] | |
|---|---|---|---|---|---|---|
| | mean | stdev | mean | stdev | mean | stdev |
| **GPS** | 2.21 | 1.18 | - | - | 0.088 | 0.44 |
| **Wheel** | - | - | 0.014 | 0.034 | - | - |
| **Radar** | - | - | - 0.012 | 0.049 | - | - |
| **Compass** | - | - | - | - | 0.068 | 0.38 |
| **Filter A** | 1.86 | 0.99 | 0.008 | 0.037 | 0.063 | 0.40 |
| **Filter B** | 1.89 | 0.97 | 0.006 | 0.035 | 0.062 | 0.43 |
| **Filter C** | 1.54 | 0.71 | - 0.009 | 0.041 | 0.072 | 0.41 |

The reliability of the dead reckoning - GPS integrating positioning system improved too. Under practical conditions dead reckoning is able to bridge 10 to 20 seconds of GPS no-fix status without dramatic accuracy decrease. The model for a position filter is most accurate with e position-velocity- acceleration state model (filter A). Extra states to model autocorrelation in the sensor signals are needed for both GPS and dead reckoning sensors (filter C). When improvement of position accuracy is the main goal of the positioning system, two extra error states for the autocorrelation factors of the GPS must be added to the system model. Calibration errors in the velocity sensors were not incorporated in the filter. However temporary velocity sensor degradations were filtered out through the implementation of extra error states similar to the mechanism for handling auto-correlation in the sensor signals.

## 4 Dynamic weighing for accurate fertilizer application

Application of mineral fertilizer in a precision agriculture system depends on site specific crop requirements and is based on the crop-soil-weather interactions. With respect to spatial variability of soil nutrients following requirement have to be met in fertilizer spreading (Van Bergeijk, 1996):

- the application rate depends on the position in the field
- the required application rate has to be realized by a correct set value of the mass flow
- the momentaneous mass flow has to be precisely distributed.

Application rate errors due to mass flow deviations have to be measured and have to be reported to the management system to analyse site specific crop response and to adjust the fertilizer strategy within a growing season.

To reduce application rate errors, several manufacturers have started to mount load cells in the spreaders to monitor the applied amount of fertilizer. The next step is the development of a dynamic weighing system, suitable for operation under field conditions in agriculture. This system should include the automatic calibration of the mass flow control device of a granular fertilizer spreader. Disturbances due to uneven terrain, mechanical vibrations of tractor and spreader and operation on slopes have to be compensated or suppressed. Methods for mass measurements of implements in the three point hitch have been described by Auernhammer et al, (1988, 1990) and Van Meeteren and Van der Heuvel, (1991). In practice problems are caused by the different hitch geometrics and by external vibrations and variations in inclination.

In the weighing system which has been developed by the Dept. of Agr. Engineering of WAU the original hitch studs of the fertilizer spreader (Amazone Jet 1504) were replaced by three spring blades on a triangular subframe. One has been placed at the top middle position of a subframe and the other two at the lower sides. The subframe has mounting positions for two strain gauge force sensors. The vertical forces of the entire spreader act on the weight sensor while the horizontal forces run parallel through the spring blades. An essential part in the system is the reference sensor which measures a calibrated weight. The mounting orientation of that reference sensor is similar to the weight sensor to ensure that both sensors are affected by the same disturbances.

Two reference sensors (Celtron LPS 2 and Celtron LOC 50 single point load cells) and one weight sensor (Tedea huntleigh 3510 G shearbeam load cell) were examined. Data acquisition was done in two ways. The first method consisted of a strain gauge amplifier connected through a low pass filter to an analog to digital conversion card in a PC. To minimize the number of noise sources in the weighing system a second data acquisition method therefore used a single integrated circuit which was directly connected to the strain gauge sensor. To connect the spreader weight sensor and the reference sensor to the data acquisition system two AD 7715 integrated circuits were used.

The static sensor response was determined by applying calibrated loads on the sensors over a range similar to the measured forces under field conditions.

A number of combinations of sensors and data acquisition systems were investigated on their dynamic weighing performance. Data was acquired on road tracks with traffic obstacles at 3 m/s driving speed. The results of the experiments are shown in **table 2**. The last row of this table gives the weight characteristics after compensation and filtering of the sampled data. From the power spectral density graph of reference sensor II, it could be seen that the resonance peak around 40 Hz required more energy to get in resonance than sensor I did. Due to this better resonance characteristic the compensation based on reference sensor II in the series B and C reduced the standard deviation of the weight readings to values below 20 N. These results seem promising for the further development of the dynamic weighing system and the implementation of automatic mass flow calibration for fertilizer spreaders. The data flow diagram of such a calibration system is presented in **fig. 4**.

Table 2: The performance of the dynamic weighing system in three experimental series
(According to Van Bergeijk et al, 1996)
*Tabelle 2: Ergebnisse des dynamischen Wägesystems in drei Versuchsserien*

| | | serie A | serie B | serie C |
|---|---|---|---|---|
| **data acquisition method** | | separate strain gauge amplifier, low pass filters and A/D card | | AD7715 sigma delta A/D convertors |
| **reference sensor (load)** | | I (1.776 N) | II (38.40 N) | |
| **total load on weight sensor** | | 9823.7 | 11312.0 | 9827.7 |
| **weight sensor signal** | standard deviation | 948.6 | 1090.9 | 1063.4 |
| | minimum | 5971.4 | 6826.8 | 6593.3 |
| | maximum | 12545.0 | 15378.2 | 12921.7 |
| **compensated and filtered signals** | standard deviation | 168.7 | 18.6 | 19.6 |
| | minimum | 9314.6 | 11241.3 | 9811.0 |
| | maximum | 10063.1 | 11396.3 | 9903.2 |

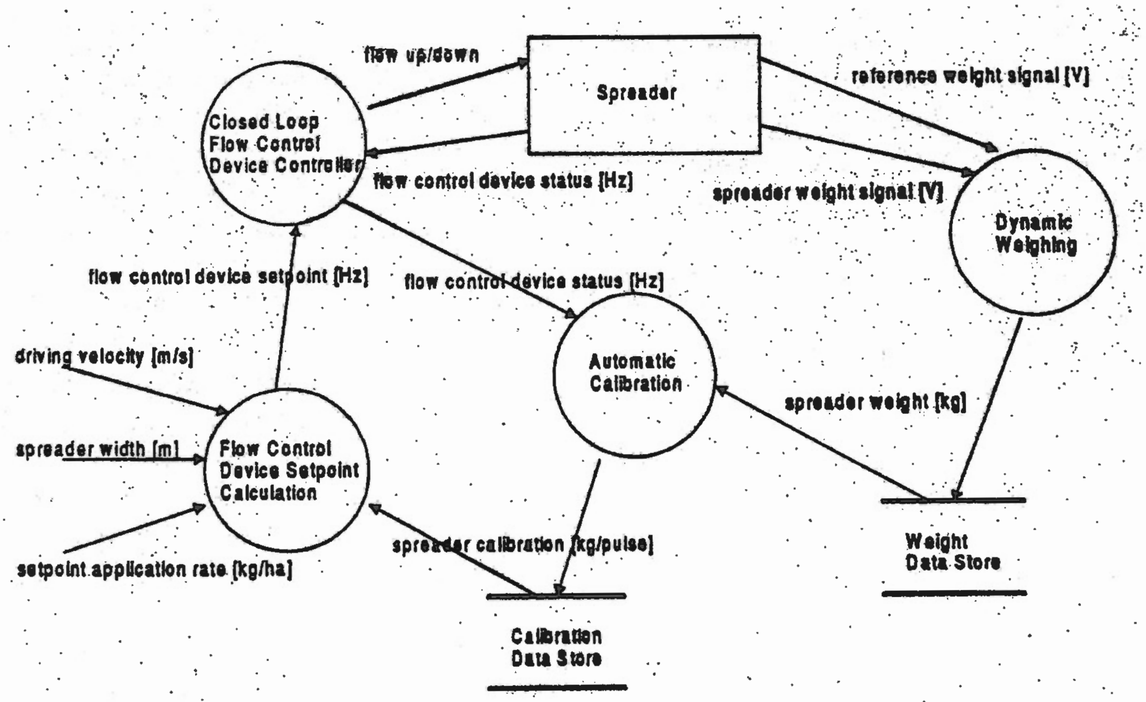


Figure 4: Data flow diagram for automatic calibration of a flow control section
(According to Van Bergeijk et al, 1996)
*Bild 4: Datenfluß-Diagramm für die automatische Kalibrierung der Mengeneinstellung eines Düngerstreuers*

**Final remarks**

Precision agriculture can contribute to a more sustainable and economic viable agriculture based on participation from various scientific disciplines like soil science, geostatistics, systems and control engineering, information technology and agronomics. Valuable research is going on all over the world. Agricultural engineering plays an important role in the further development towards implementation of these high-tech agricultural systems, based on high ecological requirements. It should be noted that this discipline is a cruxial part of this development and the related research activities.

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