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Present Status of Precision Farming: A Review

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Abstract: Precision Farming (PF) concept is spreading rapidly in developed countries as a tool to fight the challenge of agricultural sustainability. With the progress and application of information technology in agriculture, PF has been increasingly gaining attentions worldwide. Huge work has been started in different corners of the world on this subject. Knowledge on present developments helps to foresee the forthcoming challenges. Hence, this article provides an overview of development and current status of precision agriculture technologies. The topics include positioning system, yield mapping, remote sensing, variable rate technology, soil and crop sensing and information transmission standard.

Key words: Precision farming, GPS, VRT, yield mapping, remote sensing

Introduction

Non stop supply of pollutant free huge food production for the ever-increasing population as well as the challenges of free and globalized market creates the scope of introduction and adoption of modern technologies in agriculture. PF is such a new emerging, highly promising technology, spreading rapidly mainly in the developed countries. PF is a scientific approach to improve the agricultural management by application of Information Technology (IT) and satellite based technology to identify, analyze and manage the spatial and temporal variability of agronomic parameters (e.g., soil, disease, nutrient, water etc.) within field by timely application of only required amount of input to optimize profitability, sustainability with a minimized impact on environment (Mondal *et al*., 2004). Over the last 15 years, PF has gained a very high profile in the agricultural industry. Though some researcher earlier in the 20th century (Linsley and Bauer, 1929) drilled the first seeds of PF, but, it was mainly Johnson *et al*. (1983) and Mathews (1983) etc. who initiated the works of today's PF (Stafford, 2000).

With the progress and application of information technology in agriculture and IT revolution in developing countries like India, China etc., precision agriculture has been increasingly gaining attentions worldwide (Luo *et al*., 2006). A good amount of work on PF has been started in different countries. Knowledge on present status of PF helps to visualize the future challenges. Hence, this article provides an overview of development and current status of precision agriculture technologies.

Overview of PF Technology

The advanced PF technology started to develop from early eighties in the developed world. Today's PF technology is a combined result of development of different sectors, which are discussed below.

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Positioning System

Positioning system works by the help of different constellations of satellites. Development of positioning system technology by different countries was one of the main factors of advancement in PF. Global Positioning System (GPS), developed by US Department of Defense, is based on constellation of 24 satellites in 6 orbital planes with orbit period of 12 h at 55° inclination with an altitude of 12,500 mile above the earth. Similar positioning system is Russian GLONASS positioning system. A European Global Navigation Satellite System (GNSS), Galileo is also under processing. Each GPS satellite orbits, has an atomic (caesium vapour) clock, which is an international time standard. Time synchronization of the coded signals transmitted by the satellites provides the basis of the system, which allows a ground level receiver to compute its range from each satellite currently in view and hence via the measured range to three or more satellites-to compute its position on the earth's surface (Cox, 2002). Each GPS satellite continuously broadcasts two radio signals on separate L band frequencies (the L band is from 1000 to 2000 MHZ). The L1 signal, transmitted at 1575.42 MHZ, carries two codes, a coarse/acquisition (C/A) code and a precision (P) code. The L2 signal, transmitted at 1227.60 MHZ, carries only P code. Positioning system based C/A code of L1 signal is known as Standard Positioning System (SPS) and civilian users can use only this SPS (Pfost, 1998). Differential GPS (DGPS) can correct selective availability error with some limitations. Sophisticated enough commercial receivers are now available at, a reduced price (hand held, 12 channel GPS receiver's price is less than £ 100) (Stafford, 2000). Commercial sensors receiving and processing GPS signals have become affordable for most farmers in developed countries. Handheld GPS receivers provide positioning accuracy within ±100 m. Differential GPS (DGPS) reduces the error to ±2m. A relative positioning GPS brings the error down to the sub-centimeter level (Zhang *et al*., 2002). This accuracy can be maintained for moving vehicles using a real-time kinematic (RTK) GPS. RTKDGPS employs the two frequency transmissions from each GPS satellite (Kruger *et al*., 1994). Dux *et al*. (1999) used a geo-referenced audio recorder with a speech recognition capability to generate field maps during field scouting. This system allows users to record visual observations on crop growth, weeds, diseases, or other anomalies while walking or riding an All Terrain Vehicle (ATV) within a field.

A ground based network of reference stations providing correction data and other information for the users is necessary for real time, high accuracy (down to the 1 cm level) GPS positioning. This type of systems are called ground based GNSS infrastructure. There are intensive developments of such infrastructures, such as EUPOS in Central and Eastern Europe, which will be beneficial for future PF applications (Borza and Fejes, 2006). RTK DGPS can provide elevation accuracy of as good as 5 cm (Sudduth, 1998). So farther improvement by the use of more precise systems and competitive services by different countries and organizations, will make positioning technology more robust, accurate and cheap.

Yield Mapping

Yield is decisive pointer of variation of different agronomic parameters in different parts within the field. So mapping of yield and correlation of that map with the spatial and temporal variability of different agronomic parameters helps in development of next season's crop management strategy (Mondal *et al*., 2004). Present yield monitors measure the volume or mass flow rate to generate time periodic record of quantity of harvested crop for that period (Plant, 2001). Grain yields are measured using four types of yield sensors-impact or mass flow sensors, weight-based sensors, optical yield sensors and γ-ray sensors. Most major agricultural equipment companies provide optional yield-mapping systems for their combine harvesters (Zhang *et al*., 2002). Time periodic yield data is generally synchronized with location address obtained from onboard GPS system to create most common colour coded thematic map (Pierce *et al*., 1997). A simple, low cost and automatic yield mapping system was developed to generate yield maps of hand-harvested crops (Schueller *et al*., 1999). For tomato crop, a continuous mass-flow type yield sensing system, equipped with load cells and a vibration-resistant angle transducer along with a DGPS, was developed to collect real-time spatially variable yield data (Pelletier and Upadhyaya, 1999) Australian lupin and cotton yield monitor data were analyzed using spatial models from the Matérn class of spatial covariance functions (Clifford *et al*., 2006). That study found that anisotropy and convolution are properties of yield monitor data and that it is hard to distinguish the two. Properly calibrated field monitor systems are generally very accurate (<1 to 5% error) at estimating yield averages over large areas (Pierce *et al*., 1997).

We can safely tell that yield monitoring technology for grain crop is matured or near to be matured. In future, development of standard yield monitors for non grain crops is required (Mondal *et al*., 2004). Some attempts have already been stared. For forage crops, yield monitors using a displacement sensor, a load cell, a capacitance-controlled oscillator and an optical sensor have been studied (Zhang *et al*., 2002). An optical sensor measuring spectral radiance in the red and NIR wavebands was used to estimate yield during cropping seasons and to guide VRT for nitrogen fertilizer (Solie *et al*., 2000).

Remote Sensing

Remotely sensed information, containing electromagnetic data of crop can provide information useful for agronomic management. This type of information is cost effective and can be very useful for site-specific crop management programs (Plant, 2001).

Mapping of weeds against bare soil for row crops at early stages of seedlings has been carried out successfully (Lamb, 1995). As a general theory resolutions should be less than the minimum expected size of weed patch (Rew *et al*., 1997). Synthetic Aperture Radar (SAR) images from satellite like ESR2 can penetrate cloud cover. So combination of SAR images with multi-spectral images can improve spatial crop management decision (Stafford, 2000). High resolution geophysical methods, such as use of Ground Penetrating Radar (GPR), hold promise for improved and minimally invasive characterization and monitoring of the subsurface. Using 900 MHZ GPR ground-wave travel time data, estimation of spatial distribution of soil water content of top 15 cm of the soil layers has been done and it has been found that result obtained by GPR method is within 1% error level, when compared to results obtained from gravimetric and Time Domain Reflectometry (TDR) methods (Hubbard *et al*., 2005). GPR was used to produce a contour map to indicate clay lenses, which govern the magnitude and direction of ground-water movement (Dulaney *et al*., 2000). Portable GPR equipment in the 500 MHZ to 5 GHz frequency range has been employed to estimate the levels of the water table in some soils (Cox, 1997). Comparison of multi-spectral (3 band) and hyper-spectral (120 spectral bands) imaging data of leaf rust (*Puccinia recondita*) infected wheat plants revealed the suitability of hyper-spectral data for early discrimination of leaf rust due to their higher spectral sensitivity. Multi-spectral data showed a higher sensitivity to external factors like illumination conditions, causing poor classification accuracy. Nevertheless, if these factors could get under control, even multi-spectral data may serve a good indicator for infection severity (Franke *et al*., 2005). Rice yield prediction has been done using canopy reflectance. Spectrum analysis indicated that the changes of canopy reflectance spectrum were least during booting stages. So, the canopy reflectance spectra of booting stage were selected for regression model development. Results of the validation experiments indicated that the derived regression equations successfully predicted rice yield using canopy reflectance measured at booting stage unless other severe stresses occurred afterward (Chang *et al*., 2005). Spatial assessment of the physiological status of wheat crops has been done by using infrared thermal imagery. During that study, a Canopy Stress Index (CSI) has been developed which is defined as the difference between canopy (T_c) and air temperature (T_a), normalized by Vapour Pressure Deficit (VPD). CSI accounted for 80% of the variation in growth rate and yield of wheat, compared with 46-

49% explained by the normalized difference vegetation index (Rodriguez *et al*., 2005). The potential of aerial visible/infrared (VIR) hyper-spectral imagery for characterizing soil fertility factors like pH, Organic Matter (OM), Ca, Mg, P, K and soil electrical conductivity has been explored. The measured soil fertility characteristics were modeled on first derivatives of the reflectance data using Partial Least Square Regression (PLSR). The PLSR model on derivative spectra was able to explain 66% of the overall variability in soil fertility variables considered in that study. That study also revealed that some of the wavebands, such as 625, 652, 658, 661, 754 and 784 nm, explained a high degree of variability in the model, whereas a large number of wavelengths had negligible contribution (Bajwa and Tian, 2005).

Aerial Photography method has given more promising result than satellite imagery method. Compact Air borne Spectrographic Imager (CASI) used from aircraft, can give pixel resolution of 1.8 to 1 m (Portz *et al*., 1998). For multi-spectral photography generally visible red (665-700 nm), green (555-580 nm) and NIR (840-900 nm) wavelengths are most useful as they can convey information regarding vegetation (Clevers, 1988). Airborne Digital Photography (ADP) in recent days became famous with the fast development of digital camera technology.

Remotely sensed reflectance data are generally expressed in terms of different vegetation indices. Most commonly used Normalized Difference Vegetation Index (NDVI) is proved useful in estimating biomass and yield of some crops like wheat (Yuzhu, 1990). Canopy reflectance spectrum is a effective parameter to predict N stress of crop. An investigation has been carried out by measuring canopy reflectance spectrum, especially spectral red edge parameters, for winter wheat by ASD Hand-Held Spectro-radiometer (325-1075 nm) in China (Cheng *et al*., 2005). Red edge swing correlated with relative chlorophyll content and leaf N content. Area of red edge peak is the value of first-order derivative spectra accumulative total between 680 and 750 nm. That study concluded that spectral red edge parameters can be used to estimate Leaf Area Index (LAI) and N accumulating quantities and provide information for the development of variable-rate N application technology.

Although lot of experiments has been done till now, results proved that PF demands more resolution, accuracy and correlation among remotely sensed data and agronomic parameters.

Soil and Crop Sensing

Collection and analysis of soil and plant tissue sample in laboratory is time and cost intensive. In recent years many instruments have been invented based on direct contact and proximate remote sensing technology (Sudduth *et al*., 1997). Many experiments have been already proved close relationship between crop yield and soil Electrical Conductivity (EC) (Lund *et al*., 1999). Combining a soil EC probe with an automated penetrometer, soil subsurface can be mapped (Drummond *et al*., 2000). A penetrometer equipped with a near-infrared reflectance sensor measured soil penetration resistance as well as moisture content and organic matter (Newman and Hummel, 1999). Ion Selective Field Effect Transistor (ISFET) has been proved superior to Ion Selective Electrode (ISE) in several respects like high signal/noise ratio, fast response etc. Generally, direct measurement of soil conductance are made by entering an electrode-equipped cutting disc through the field and indirect inductance measurements are done by taking point samples by hand-held device like non-contact electromagnetic induction probe (Plant, 2001). *In situ* measurement of apparent soil Electrical Conductivity (EC_a) is an important tool for determining spatial changes in soil properties. Measured EC can be correlated well with a soil productivity index, which combines effects of bulk density, water-holding capacity, salt and pH (Myers *et al*., 2000). EC measured before planting can be related to plant-available-water-holding capacity (Morgan *et al*., 2000). Three near-surface geophysical methods are available for rapid, continuous measurement of ECa in agricultural fields. These methods are electromagnetic induction (EMI), Capacitively Coupled Resistivity (CCR) and Galvanic Contact Resistivity (GCR) (Allred *et al*., 2006). A portable soil Electrical Conductivity (EC) detector was developed by adopting a four-electrode method. The performance test showed that the measured voltage drop had high correlation with soil ECs obtained from soil extract solution. The best correlation estimation was observed with power-function model ($R^2 = 0.994$), which made that EC meter quite acceptable for practical use (Li *et al*., 2006). In France, an eight-rolling-electrode sensor was developed to measure soil EC at three depths (Dabas *et al*., 2000). A near infrared (NIR) soil sensor measured soil spectral reflectance within the waveband of 1600-2600 nm to predict soil organic matter and moisture contents of surface and subsurface soils (Hummel *et al*., 2001). Feiffer *et al*. (2003) developed a Hydro N-Sensor to determine the N status of the crop and deduce its N fertilizer demand. Spectral measurements of canopy reflectance allow to detect differences in crop N status within a field. Connected to a variable rate spreader or sprayer, this enables an on-line site-specific N application according to the actual N demand of the crop. That method increased yield, reduce lodging and lead to more homogeneous crop stands. Nitrogen demand of winter wheat (*Triticum aestivum* L.) and triticale (*Triticosecale wittm.*) was determined by reflection measurements of on-the-go sensors throughout the growing season and the corresponding amount of N fertilizer was broadcasted with the N-Sensor (Yara, Germany) in real-time. The sensor uses the red edge position (720-740 nm) as an indicator of crop N status and relates this to crop N demand. The sensor algorithm is designed to stimulate plant growth in areas with low biomass and reduce risk of lodging in areas with high biomass. Fertilization was evaluated by calculating site-specific N balance maps to delineate zones with N surplus in the soil. The results revealed some general limitations of this sensor approach in areas with yield-limiting factors other than N (Zillmann *et al*., 2006). The results of that study indicated that sensor-based measurements can be used efficiently for variable N application in cereal crops when N is the main growth-limiting factor. A nice review of presently available real-time Nitrogen sensors has been made by Lowenberg-DeBoer (2004). He reported that at least three companies are marketing systems for nitrogen application. From an economic point of view one of the key advantages of these systems is that they eliminate the need for a separate step to create recommendation maps and the management time. He also effectively pointed out some key limitation points of real time nitrogen sensing like sensors based on reflectance (i.e., N-Sensor, GreenSeeker) must be used in growing crops, problem of correct reference point setting for N recommendation rate, need for round the clock operation etc.

Making the sensor technology cheap and suitable for developing countries is another challenge, in front of PF revolution (Mondal *et al*., 2004). Some sort of innovative measures like use of biodegradable material etc. can be promising to bring down the cost (James *et al*., 2006). Dynamic soil pH measurement, leaf fluorescence interpretation and correlation with crop status etc. are few areas on which researches are going on to make analysis of soil and crop more accurate for PF.

Variable Rate Technology (VRT)

Existing field machinery with added Electronic Control Unit (ECU) and onboard GPS can fulfill the variable rate requirement of crop. Bennett and Brown (1999) developed a direct nozzle injection system for herbicide application. An innovative distributed control system between individual sensors and actuators, a supervising controller and a navigation system was designed and installed to control spray droplet size and application rate for agricultural chemicals (Stone *et al*., 1999a). Spray booms, spinning disc applicator with ECU and GPS have been used for patch spraying (Miller and Paice, 1998). Granular applicators equipped with VRT have gained popularity in recent years as a result of increased interest in variable-rate application. Swisher *et al*. (1999) designed an optical sensor to measure flow rates of granular fertilizer in air streams for feedback control of a variable-rate spreader. Uniform-rate (UR) tests were conducted to assess the accuracy of variable-rate application from four granular applicators: two spinner-disc spreaders and two pneumatic applicators. That experiment showed potential application errors with VRT and the need for proper calibration to maintain acceptable performance. Further, that investigation demonstrated the need for a VRT equipment testing standard (Fulton *et al*., 2005). Some researches showed that residual N calculation for only topsoil is not effective for some crops like corn due to high mobile nature of NO3. For some soil, residual N and potentiality of N-mineralization of that soil during crop growth should be taken into consideration for N application map preparation for VRT application. Plant scale treatment by using spatial resolution, internal guidance and precision spray nozzles has already been achieved (Hague *et al*., 1997).

Future research in VRT should be concentrated in development of 'true precision patch sprayer, equipment, more accurate granular fertilizer applicator and their standard.

Information Transmission in PF

Type and amount of information collected and transmitted among different mobile and static electronic equipments used in agriculture are increasing rapidly which create requirement for standardized format. In Europe, German agricultural engineers have taken the lead in establishing standardized data transfer on field machines (Speckmann and Jahns, 1999). They have developed Landwirtschaftliches BUS-System (LBS), which is a version of the Controller Area Network data bus (CAN) developed by the Bosch company in the late 1980s. LBS is now a German (DIN) standard (Cox, 2002). Need of globalized standardization of electronic communication used in agriculture gave genesis of ISO-11783. Drafts of the five part DIN 9684 functions as a basis to develop ISO-11783. Different components of ISO-11783 are the Physical layer, Data link layer, Network layer, Addressing and naming and initialization, Virtual terminal, Task controlling etc. (Stone *et al*., 1999b). ISO-11783 will make information transfer for electronic communication used in PF smooth and efficient between operator and equipment made by different manufacturers (Mondal *et al*., 2004).

The safe and reliable transfer of data from field machines to the farm office for management purposes is also of increasing importance, as farm managers seek to improve efficiency in a competitive environment and to provide the detailed information on their operations required by administrative agencies of various kinds (Cox, 2002). For field machines Auernhammer *et al*. (2000) therefore suggest the integration of the LBS/DIN system with GPS and an implement indicator (IMI) which helps in automatic identification of implements. However, they recognize that its adoption requires co-operation among all the major suppliers of tractors and implements, if this is to become an open system. The means of transferring digital data from machine to office has been mainly the plug-in card of the PCMCIA type, although radio transmission offers another option, in suitable conditions (Cox, 2002; Auernhammer, 2001).

Further improvement of ISO 11783 should include smart transducer concept, defined by IEEE 1451 smart transducer standards. As PA technology advances, modular design and plug-and-play capabilities have become a future trend that would be appreciated by sensor manufacturers, system integrators, as well as farmers. So, improved ISO 11783 standard, modified in light of IEEE 1451 standards, should meet the challenges of future needs of PA applications (Wei *et al*., 2005).

Conclusions

Present time is the era of biotechnology and Information technology revolution. Crop genetic manipulation-in the interests of growth efficiency; stress tolerance and food quality for human and animal nutrition will require physical or chemical sensors to monitor microclimate and pest infestation, possibly augmented by indicator plants. These plants would be genetically tailored to signal changes in their environment in ways that could be monitored in real-time (in other words, an extension of the speaking plant concept). They would provide inputs to management models. Improved growth efficiency could lead to more precise control of crop inputs, in association with detailed terrain mapping, linked to position sensing (Cox, 2002). Krutz and Schueller (2000) predicted that the coming decade will feature multidisciplinary research teams of scientists and engineers, working on new materials, biosensors, bioelectronics and micro-electro-mechanical systems. PF has created scope of transforming the traditional agriculture, through the way of proper resource utilization and management, to an environmental friendly sustainable agriculture (Mondal *et al.*, 2004). Application of artificial neural networks, genetic algorithms, fuzzy logic, smart microprocessors, smart plant, biosensors along with other future development areas already discussed will make PF not only suitable for developed countries but also for developing countries, if applied properly.

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