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Remote Sensing Applications in Precision Agriculture

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Abstract

Precision agriculture (PA) entails the application of a suite of such technologies to optimize agricultural inputs to increase agricultural production and reduce input losses. Use of remote sensing technologies for PA has increased rapidly during the past few decades. The unprecedented availability of high resolution (spatial, spectral and temporal) satellite images has promoted the use of remote sensing in many PA applications, including crop monitoring, irrigation management, nutrient application, disease and pest management, and yield prediction. Remote-sensing-based PA technologies such as variable fertilizer rate application technology in Green Seeker and Crop Circle have already been incorporated in commercial agriculture. Given the complexity of image processing and the amount of technical knowledge and expertise needed, for the real-time application of remote sensing in PA. Development of accurate yet easy to use, user-friendly systems is likely to result in broader adoption of remote sensing technologies in commercial and non-commercial PA applications.

Introduction

Precision agriculture (PA) is a key component of sustainable agricultural systems in the 21st century (Awokuse and Xie, 2015). PA has been defined in multiple ways, yet the underlying concept remains the same. Emerging technologies, such as remote sensing, global positioning systems (GPS), geographic information systems (GIS), Internet of Things (IoT), Big Data analysis, and artificial intelligence (AI) are promising tools being utilized to optimize agricultural operations and inputs aimed to enhance production and reduce inputs and yield losses. AI techniques, including machine learning (e.g., artificial neural networks) have been used to estimate ET, soil moisture, and crop predictions for automated and precise application of water, fertilizer, herbicide, and insecticides. These state-of-the-art technologies for the development and implementation of site-specific management are integral part of PA.

Definition of Precision Agriculture

"Precision Farming" is the title given to a method of crop management by which areas of land/ crop within a field may be managed with different levels of input depending upon the yield potential of the crop in that particular area of land (Gebbers and Adamchuk, 2010). The benefits of so doing are twofold:

- The cost of producing the crop in that area can be reduced, and
- The risk of environmental pollution from agrochemicals applied at levels greater than those required by the crop can be reduced.

Precision farming is an integrated agricultural management system incorporating several technologies. The technological tools often include the followings.

• Global Positioning System (GPS),

• Geographical Information System (GIS),

• Yield Monitor (YM),

• Variable Rate Technology (VRT), and

• Remote sensing (RS).

The *Global Positioning System (GPS)* is a network of satellites developed for and managed by the US Defence Department. The GPS constellation of 24 satellites orbiting the earth, transmit precise satellite time and location information to ground receivers. The ground receiving units are able to receive this location information from several satellites at a time for use in calculating a triangulation fix thus determining the exact location of the receiver.

A *Geographical Information System (GIS)* consists of a computer software data base system used to input, store, retrieve, analyze, and display, in map like form, spatially referenced geographical information.

Yield Monitors (YM) are crop yield measuring devices installed on harvesting equipment. The yield data from the monitor is recorded and stored at regular intervals along with positional data received from the GPS unit. GIS software takes the yield data and produces yield maps.

Variable Rate Technology (VRT) consists of farm field equipment with the ability to precisely control the rate of application of crop inputs and tillage operations.

Remote Sensing (RS) image data from the soil and crops is processed and then added to the GIS database.

Application of Remote Sensing in Precision Agriculture

Soil and Drainage Maps

Soil maps are also sometimes used to determine management zones. Soil maps are becoming part of the GIS database. The grid sampling technique takes separate soil samples from uniform sized grids laid out over the field. A problem with this type of sampling is the variability that can exist in soil types within each grid. This variability makes it much tougher to determine soil characteristics within the grid for crop input management purposes. To minimize this problem smaller grids are required which then requires many more soil samples to be take for a larger number of grids. Soil samples can become a major cost of precision farming.

An alternative to grid sampling is targeted or zone sampling. The soil samples are located in homogeneous management zones instead of uniformly spaced grids. The zones are laid out using a process similar to computer based unsupervised image classification. Images obtained from multispectral remote sensors are taken of the vegetated areas of the field. The pixel digital numbers for each band are separated into statistically separable clusters that are classified into homogeneous zones. This cuts down on the soil, terrain, plant growth, and other variability within each area to be managed; thus fewer soil samples are needed for each area. Except for county soil surveys remote sensing has not gained wide acceptance as a mapping tool for soil characteristics. This is because "the reflectance characteristics of the desired soil properties (e.g., organic matter, texture, iron content) are often confused by variability in soil moisture content, surface roughness, climate factors, solar zenith angle, and etc.

Variable Rate Technology (VRT)

One method of controlling variability within the field is VRT. VRT allows the grower to apply the quantity of crop inputs needed at a precise location in the field based on the individual characteristics of that location. Crop inputs that can be varied in their application commonly include tillage, fertilizer, weed control, insect control, plant variety, plant population, and irrigation. Typical VRT system components include a computer controller, GPS receiver, and GIS map database. The computer controller adjusts the equipment application rate of the crop input applied. The computer controller is integrated with the GIS database, which contains the flow rate instructions for the application equipment. A GPS receiver is linked to the computer. The computer controller uses the location coordinates from the GPS unit to find the equipment location on the map provided by the GIS unit. The computer controller reads the instructions from the GIS system and varies the rate of the crop input being applied as the equipment crosses the field. The computer controller will record the actual rates applied at each location in the field and store the information in the GIS system, thus maintaining precise field maps of materials applied. Although VRT can control inputs applied to crops, it cannot control factors such as soil type, weather climate, and topography that are fixed. Economic feasibility of variable-rate nitrogen application utilizing site-specific management zones were reported by Kosh *et al.,* (2004).

Monitor Crop Health

Remote sensing data and images provide farmers with the ability to monitor the health and condition of crops. Multispectral remote sensing can detect reflected light that is not visible to the naked eye. The chlorophyll in the plant leaf reflects green light while absorbing most of the blue and red light waves emitted from the sun. Stressed plants reflect various wavelengths of light that are different from healthy plants. Healthy plants reflect more infrared energy from the spongy mesophyll plant leaf tissue than stressed plants. By being able to detect areas of plant stress before it becomes visible, farmers will have additional time to analyze the problem area and apply a treatment.

Water Stress

The use of remote sensors to directly measure soil moisture has had very limited success. Synthetic Aperture Radar (SAR) sensors are sensitive to soil moisture and they have been used to directly measure soil moisture. SAR data requires extensive use of processing to remove surface induced noise such as soil surface roughness, vegetation, and topography. A crop evapotranspiration rate decrease is an indicator of crop water stress or other crop problems such as plant disease or insect infestation. Remote sensing images have been combined with a Crop Water Stress Index (CWSI) model to measure field variations. Simple panchromatic aerial photographs have been used to spot irrigation equipment problems. Strips in the vegetation images point to problems with water application rates from defective water nozzles.

Weed Management

One goal of precision farming is to cut crop production inputs, which result in cost and environmental savings. Conventional farming methods apply herbicides to the entire field. Site-specific variable-rate application puts the herbicide where the weeds are. Aerial remote sensing has not yet proved to be very useful in monitoring and locating dispersed weed populations. Some difficulties encountered are that weeds often will be dispersed throughout a crop that is spectrally similar, and very large-scale high resolution images will be needed for detection and identification. The use of machine vision technology systems to detect and identify weeds places remote sensors directly on the sprayer equipment. Being close to the crop allows for very high spatial resolutions. Machine vision systems have the ability to be used in the field with the real-time capabilities that are necessary to control sprayer equipment.

Insect Detection

Aerial or satellite remote sensing has not been successfully used to identify and locate insects directly. Indirect detection of insects through the detection of plant stress has generally not been used in annual crops. The economic injury level for treatment is usually exceeded by the time plant stress is detected by remote sensing. Entomologists prefer to do direct in field scouting in order to detect insects in time for chemical treatments to be effective and economical.

Nutrient Stress

Plant nitrogen stress areas can be located in the field using high-resolution colour infrared aerial images. The reflectance of near infrared, visible red and visible green wavelengths have a high correlation to the amount of applied nitrogen in the field. Canopy reflectance of red provides a good estimate of actual crop yields.

Yield Forecasting

Plant tissue absorbs much of the red light band and is very reflective of energy in near infrared (NIR) wavebands. The ratio of these two bands is referred to as the vegetation index (VI). The difference of red and NIR measurements divided by their sum is normalized difference VI (NDVI). For crops such as grain sorghum, production yields, leaf area index (LAI), crop height and biomass have been correlated with NDVI data obtained from multispectral images.

Management Decision Support Systems

Just having information about variability within the field doesn't solve any problems unless there is some kind of decision support system (DSS) in order to make VRT recommendations.

Major Steps for a DSS:

• Identify environmental and biological states and processes in the field that can be monitored and manipulated for the betterment of crop production.

• Choose sensors and supporting equipment to record data on these states and processes.

• Collect, store and communicate the field-recorded data.

• Process and manipulate the data into useful information and knowledge.

• Present the information and knowledge in a form that can be interpreted to make decisions. This DSS helps to make more favourable and profitable crop production.

Conclusion

A large number of advanced techniques, including empirical, regression, and various forms of machine learning approaches have been used to explore the potential applications of remote sensing in PA. Similarly, many vegetation indices have been developed and tested for their ability to help PA operations, including variable fertilizer management, irrigation scheduling, disease control, weed mapping, and yield forecasting. However, many challenges need to be addressed before the remote sensing technologies can potentially see a large-scale adoption in commercial and non-commercial agriculture.

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