Remote sensing – adapting to change

By John Shanahan, University of Nebraska, USDA

Precision farming (PF) is an agricultural technology that involves optimising agricultural input application on a site-specific basis, thereby reducing waste, increasing profit, and minimising environmental impact.

Remote sensing is one of the key tools in PF, and is an important source of data for site-specific crop management, providing both spatial and temporal information about soil and crop conditions.

It allows detection and/or characterisation of objects without being in physical contact with the object from remote platforms such as ground-based sensors, aircraft and satellites.

Consultants' Corner

Consultants' Corner is an initiative by *Australian Grain* highlighting current GRDC-funded research with a particular focus on the commercial implications of adopting cutting-edge research.

In the US, research with remote sensing traces back to the mid 1950s, when it was shown that aerial infrared photography could be used to detect loss of vigour from disease in wheat and other small grains. Application of remote sensing tools to monitor soil and crop conditions has progressed to offer valuable quantitative and near real time information over large areas.

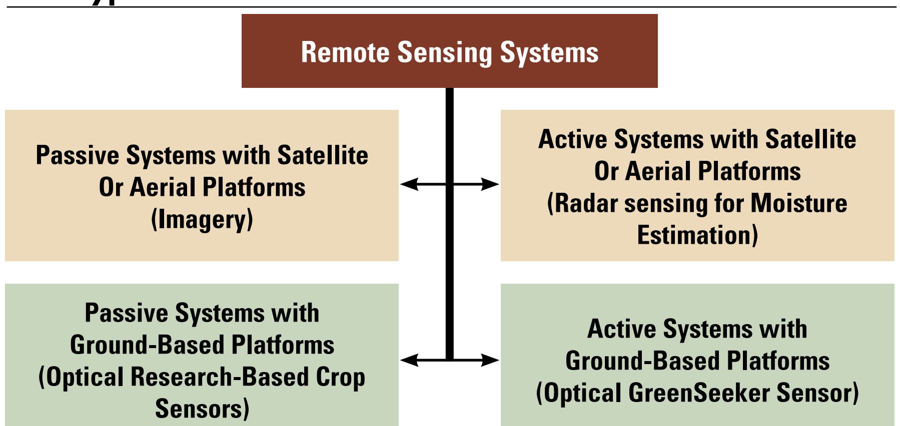
The types of sensors commonly used today for remote sensing are part of either passive or active systems. Active sensors such as radar or optical canopy sensors supply their own source of energy to illuminate target surfaces. Passive systems, like a common camera, detect reflected solar energy. Platforms that support the sensor vary, depending on the platforms' altitude above the target.

Today, two main observation platforms are used to collect remote sensing data – aerial or satellite based and ground based. A simple classification of remote sensing systems is shown in Figure 1.

This article reviews:

- Various remote sensing systems;
- What systems are commercially available; and,
- What is driving change to use various systems.

FIGURE 1: Variety of remote sensing systems and examples for each type



A ute-mounted Yara N-Sensor for mapping a crop trial. In commercial applications the sensor would normally be mounted on a tractor cab for on-the-go control of a spreader.

Various remote sensing systems

During the past 50 years, remote sensing instrumentation has developed from simple optical systems into complex digital sensors, allowing rapid and high quality scanning of the Earth's surface. Computation algorithms have been developed to process remotely sensed data and to produce different types of images.

Spatial, spectral, radiometric and temporal resolutions are the main characteristics of any remote sensing system. Spatial resolution refers to the smallest area (pixel) that can be distinguished in the image.

Most images and data sets used in site-specific management have spatial resolutions ranging from less then a metre to 20 metres or more. Smaller pixel size usually is more expensive and requires more storage space and computation power. Spectral resolution defines the ability of the system to differentiate between levels of electromagnetic radiation across different wavelengths (portions of spectrum).

The visible to near-infrared range of the spectrum (400–700 nanometres) provides the greatest insight into soil and crop conditions. Useful information can also be ob-

tained from other portions of the spectrum such as the mid-infrared, and thermal. The number of sensed portions of the spectrum (bands) and their width also characterise the spectral resolution of the system.

Some sensors (especially photographic) produce only black and white, colour, or colour infrared images, while other digital sensors allow recording multi-spectral or hyper-spectral responses.

Radiometric resolution is a term used to describe a remote sensing instrument's sensitivity, with most current systems producing 8-bit data. Temporal resolution refers to the time between sequential data collection events using the same source.

This is especially important while studying crop growth conditions.

The schedule of orbiting satellites and planned aircraft missions does not always allow obtaining data in favourable weather conditions and at the desired times. Delays in data delivery have been a limiting factor.

To avoid some of the problems associated with aerial or satellite based passive sensor systems, we can use recently developed active sensor systems. These function by illuminating the target with modulated light generated with light emitting diodes (LED) and measuring the amount of modulated light reflected from the target back to the sensor. Photodiode detectors, sensitive to the modulated light of selected wavebands, are used to measure this reflectance.

South Australian based consultant and precision farming researcher, Sam Trengove with a tractor-mounted Yara N-Sensor.

These active sensor systems are generally mounted on high-clearance vehicles positioned over the soil or crop surfaces of interest. They are capable of making on-the-go assessment of soil or crop conditions as accurately as passive systems, and can operate with/without natural sunlight.

Active sensor measurements of canopy reflectance are converted to vegetative indices similar to those used for passive remote sensing techniques.

Other applications of these active sensors are for herbicide application to selected areas which can be conducted by application systems capable of weed identification based on leaf patterns or reflectance values. Success with these techniques has been limited and cost and technology development have prohibited large-scale inception. But new algorithms with improved weed and crop characterisation capabilities using know-how technology called 'Machine Vision' are currently under development.

Another opportunity for vehicle-based systems is active sensors targeting subsurface soil reflectance. These sensors are not sensitive to crop residue coverage and may improve quality of information about spatial and depth variation of selected soil properties. Research – and limited commercial applications – are available at this time.

Most remotely sensed data can be imported into a Geographic Information System (GIS) database to overlay with other layers of information such as yield maps and soil sampling locations.

A hard copy of obtained imagery (like a 35 mm film) can be scanned into the GIS

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TABLE 1: Selected satellite and aerial imagery data sources

Service	Type	Spectral range	Number of bands	Spatial resolution	Revisit
SATELLITE IMAGERY					
AVHRR	Multi-spectral	580–1250 nm	5	1 km	Daily
SeaWIFS	Multi-spectral	402–885 nm	8	1 km	Daily
Landsat	Multi-spectral	450–1250 nm	7 + Pan*	30 m	16 D
Spot	Multi-spectral	500–890 nm	4 + Pan	20 m	26 D
IRS	Multi-spectral	450–900 nm	4	72 m	22 D
IKONOS	Multi-spectral	445–853 nm	4 + Pan	4 m (1 m Pan)	2-3 D
Quick Bird	Multi-spectral	450–900 nm	4 + Pan	2.5 m (0.6 m Pan)	2-5 D
AERIAL IMAGERY					
Duncan Tech	Multi-spectral	400–1100 nm	3-5	1 m	Daily
ADAR	Multi-spectral	450–860 nm	4	1 m	"
AISA	Hyper-spectral	400–900 nm	Up to 288	1 m	"
CASI	Hyper-spectral	400–1000 nm	288	1 m	"
35mm colour film	Broadband	400–700 nm	3	1 m	"
35mm colour infrared film	Broadband	500–900 nm	3	1 m	"
Black and white film	Panchromatic	400–700 nm	1	1 m	"
Digital colour camera	Broadband	400–700 nm	3	1 m	"
Digital colour infrared camera	Broadband	500–900 nm	3	1 m	"

*Pan refers to panchromatic (black and white) images

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to compare observed field patterns and to identify field anomalies. Various GIS and mapping software packages have different analytical capabilities to process digital and scanned images. But in every case it is necessary to make sure that remotely sensed data are rectified using proper geographic coordinates.

In other words, each image should be scaled and oriented according to true geographic coordinates of every pixel. Once the data are in digital format, various analytical algorithms can be applied.

Commercially available systems

Some of the most popular commercial sources of satellite or aerial remotely sensed imagery services are listed in Table 1. Aerial or satellite imagery have recently become primary tools for assessing the properties of soil and crop surfaces. Satellite or aerial images obtained when vegetative coverage is not significant are often called 'Bare Soil Images'. These data can be used to identify areas of the field with similarities in terms of many physical soil properties. The patterns of bare soil images in many instances reproduce the soil type survey maps, and often more accurately.

Digital Orthophoto Quadrangles (DOQ) is the most popular imagery that can be downloaded from various data bank web sites (such as, http://glovis.usgs.gov/ and http://datagateway.nrcs.usda.gov/).

These types of images are being used to develop management zones, which can in turn be used to direct soil sampling for assessment of soil nutrient status or as prescription maps as input for variable application of various soil nutrients or amendments.

Remote sensing images taken over crop canopies throughout the growing season using vegetative indices like NDVI and GNDVI are becoming commonplace. These products (often referred to as 'Crop Vigour' or 'Vegetation Status' maps) can be used to guide nutrient management, weed control, growth regulator application and irrigation.

The active sensor systems that are commercially available in the US are the GreenSeeker by N-Tech (http://www.ntechindustries.com), the Crop Circle manufactured by Holland Scientific (http://www.hollandscientific.com) and distributed by AgLeader (http://www.agleader.com), and the N sensor by Yara (http://fert.yara.co.uk/en/).

These vehicle-based active optical sensors have been incorporated into closed-loop, real-time, variable rate application systems. These sensors play the role of a 'seeing-eye'.

The main components of variable rate applicators are irradiance and/or radiance sensors, a master control unit, and nozzles with solenoid valves. As the implement travels through the field, the data obtained from the crop irradiance/radiance detector is interpreted by a microprocessor that controls the corresponding solenoid valves, thus turning on and off the spray nozzles.

Real-time systems are capable of applying necessary adjustments to application rates of crop amendments on-the-go.

What is driving change to use various systems?

Conventional management schemes often lead to inefficient application of fertiliser, pesticide and seed inputs. With conventional nitrogen management for example, it's been estimated that fertiliser use efficiency is only in the range of 30–50 per cent. The lost N associated with these current schemes represents a multi-billon dollar annual cost to global agriculture and results in environmental contamination.

This alone is a major impetus to implement more effective management schemes for application of crop inputs.

Examples of the successful use of remote sensing technologies for more efficient application of crop inputs include:

- The use of satellite/aerial imagery in collecting bare soil images in the development of management zones for variable rate application of crop nutrients. This approach is much more efficient than traditional soil grid sampling methods (less labour and fewer soil samples to be analysed) for managing crop nutrients.
- The use of aerial imagery of crop canopies to make variable rate applications of growth regulators to crops such as cotton.
- The use of active canopy sensors attached to fertiliser spreaders for variable rate application of N to crops like wheat and maize.

While additional adaptive research is needed to refine these active sensor technologies and subsequent N management algorithms, preliminary results are encouraging. It is expected N use efficiency can be greatly enhanced using this plant-based responsive strategy.

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THE COMMERCIAL VIEW

By Sam Trengove, Allan Mayfield Consulting

Crop sensing technology provides a measure of crop growth and its variability, and it has been available to growers globally for some time from satellites and airborne imaging systems. The past 10 years has seen the development of ground-based sensors – that when combined with GPS location – provides similar information about variability in crop growth as remote sensing systems.

This now provides growers with options ranging from using a satellite or aerial imagery service provider to owning your own ground-based system that is mounted on your tractor or boom for real time data collection and use.

There are many potential causes of variability in crop growth, including variability in soil water availability, crop rooting depth, root and foliar disease pressure, sodic, saline or compacted soils and nutrient deficiencies or toxicities. In most cases these effects express themselves in the crop through reduced growth and vigour. Crop sensors provide an accurate measure of the variability in crop growth caused by these effects, but the causes of variability still need to be identified.

A map of the variability in crop growth can tell you how much difference in

Sam Trengove.

growth there is across a paddock, how much of the crop can be classified as better or poorer and target where to go and look for the causes of variability. Other layers of information (such as soil maps) may also help to explain what the causes are, and farmer knowledge often provides useful insights into the causes of variability. Once the cause or causes of variability have been identified, a decision on how best to manage the crop can be made.

Areas of paddocks with greatest crop growth are areas with the least limiting conditions for crop growth, while areas with poorer crop growth are areas where growth has been constrained the most. Liebig's law of the minimum (see Figure 1) is essentially varying across the paddock. This is a snapshot in time and the variability across a paddock can change as the balance of factors limiting crop growth change during the season. This is particularly obvious where soil water constraints come into play later in the season – as it has in most cropping regions in the past three seasons.

These factors will determine the relationship between in-season crop growth measurements at the time of sensing and final grain yield.

Crop sensing for N management

There have been many investigations into the use of crop sensing information for nitrogen management; given it is a significant crop input cost that is incurred annually. The greatest adoption of crop sensing for nitrogen management has probably been realised in Europe, and for good reason. Many European farmers have legislated limits imposed on them regarding how much nitrogen they can apply, with rates targeted near 90 per cent of the economic optimum. This means that nitrogen is often the limiting factor and farmers are using this technology to redistribute nitrogen to where it is needed the most.

In the US the term 'N-rich strip' has been coined to describe a method to gauge the responsiveness of a crop to nitrogen applications. Farmers create N-rich strips by applying luxury rates of nitrogen to strips across different soil types in paddocks, ensuring that crop growth is not limited by nitrogen. Crop sensors are then used to compare crop growth within the N-rich strip with adjacent crop and the difference in growth between the two gives an indication of the nitrogen responsiveness of that crop.

This responsiveness is termed the response index and the change in response index across the paddock according to the variability in crop growth can be used to formulate a variable rate nitrogen application. In paddocks with highly variable soil types it is important that an N-rich strip is placed in all soil types as the nitrogen responsiveness in different soil types may be affected by the availability of other resources in that zone.

Crop sensing technology in Australia

Crop sensing technologies have not seen widespread adoption in Australia – yet. But growers who are using the technology use it in a variety of ways including for crop scouting and identifying problem areas in paddocks that are not performing to their potential. Where inputs are manageable, this information is then used to target the correct inputs for those areas. This may be increasing the rates of a limiting nutrient to correct a nutrient deficiency, or alternatively, reducing crop inputs in those areas to be in balance with crop yield potential if there is a long-term soil constraint that cannot be ameliorated.

High resolution (1m) aerial imagery has been used to identify human induced variability within paddocks caused by inaccurate seeding and spreading equipment, which has then been rectified.

The evaluation of crop-sensing technology for variable nitrogen applications continues. The use of N-rich strips has been evaluated at some Australian sites and showed some promise, and work will continue in refining this technique. Work also continues in gaining a better understanding of the nitrogen and water balances in our cropping systems and how information collected from crop sensors during the growing season can improve this understanding and improve in-season decisions on nitrogen use.

Site-specific weed management

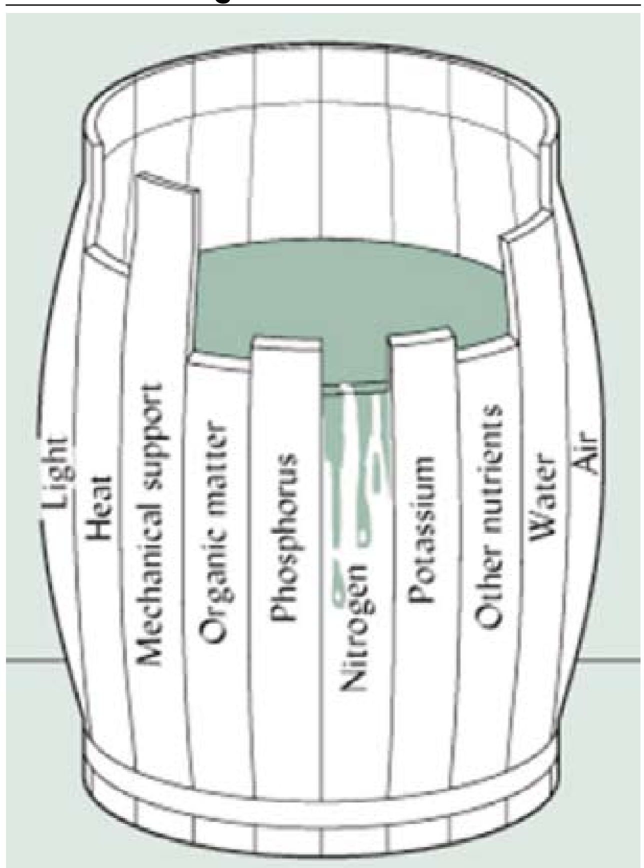
I am also doing a Masters study on using this same crop sensing technology to map weeds within crops and target herbicide trials to assess the potential for site-specific weed management (SSWM).

The greater vegetative vigour associated with weed patches is enabling us to identify problem weed areas within paddocks – this has been particularly effective in mapping problem ryegrass areas in canola and grain legumes at early growth stages, before crop variability confuses the mapping process. This information gives us the potential to target more effective weed control measures.

We are also working to determine if problematic ryegrass patches are stable between seasons. In many cases they are, which enables farmers to use historical weed maps for application of pre-emergent herbicides and increased seeding rates for increased weed control and crop competition in subsequent years before weeds have emerged. Research in this field is continuing overseas as well, with machine vision mapping systems that can identify and count different weed species within the growing crop based on plant features including leaf shapes, angles and size.

NOTE: Sam Trengove travelled to Europe and the US to study crop sensing technology for applications in crop and weed management as the recipient of a GRDC-sponsored travel grant and also supported by a Council of Australasian Weed Societies student travel award.

FIGURE 1: Liebig's law of the minimum



The yield potential of a crop is like a barrel with unequal staves. The capacity of the barrel is limited by the stave of shortest length. The capacity of the barrel is only increased by lengthening the shortest stave until another stave becomes limiting. The full capacity of the barrel represents the genetic yield potential of the crop.