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How Wireless Will Change Agriculture

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Abstract

At the dawn of the 21st century, there is a wireless revolution. Yet, this revolution appears to be conspicuously absent in agriculture despite technological advances which make it conceivable to build and deploy wireless sensor and control networks which would radically improve farm efficiencies. This is because current wireless technologies are too expensive, too unreliable or too complicated for the farm. However, that is about to change because of the rapid pace of development in certain sectors of internet communications. It is the opinion of the authors that wireless networks may offer the same type of quantum leap forward for farming that GPS provided during the past decade. Internet networks are set to eclipse the capabilities of all previous forms of distance communication and will provide the communications backbone for farms in the future

Keywords: wireless networks, internet, sensors, WLAN.

Introduction

For many, the term 'wireless' is daunting because it brings forth a whole lexicon of additional terms and acronyms such as WiFi, ZigBee, RFID, WLAN, Bluetooth and 802.11x that are new and intimidating. But what does wireless truly mean? Today, it is most commonly defined as any type of electrical or electronic operation which is accomplished without the use of a "hard wired" connection (Wikipedia, 2006). For nearly two decades, the most important wireless application was the television remote control. But in the last decade, that has been surpassed by the spectacular growth of cellular networks and wireless broadband internet. Wireless broadband internet networks are widespread. PDAs (personal digital assistants) such as the ubiquitous Blackberry® which combine cellular phone service, internet access and computing services are in general use. Despite the spectacular growth of cellular networks, predictions are that they will occupy as little as 3% of the available wireless bandwidth by the end of the decade (Sensors Magazine, 2004; Wang et al., 2006).

The consensus is that at the dawn of the 21st century, there is a wireless revolution. With some exceptions, this revolution appears to be largely absent in agriculture. Precision agriculture and precision livestock farming – disciplines heavily reliant on data collection and subsequent control, have not taken advantage of these technologies as much as other business sectors. This paper addresses the lack of take up of wireless networks as well as looking at the potential for adoption of wireless technologies in agriculture.

The state of wireless applications in agriculture

Competitive pressures and economies of scale are forcing farms to become larger. In many cases, this means that farms are also becoming more dispersed as farmers purchase or rent non-contiguous properties. Consequently, farmers are spending more and more time and energy traveling between locations as they monitor ongoing activities such as irrigation, planting, harvesting and grain drying, or check on livestock; collect information from rain gauges, soil moisture sensors and other devices; control equipment (start pumps, close gates, etc); and communicate with employees. Technological advances make it conceivable to build and deploy wireless sensor and control networks to automate many of these tasks.

However, most farms do not have remote sensing and control capabilities. Farmers do not like wasting time and fuel and would not drive to a remote part of the farm to check on an employee or turn on an irrigation pump if there was a better way. That these tasks are not done remotely bears testimony to the fact that current wireless technologies are too expensive, too unreliable or too complicated (or any combination of the above) for the farm (Pocknee, 2005).

Yet it is wrong to assume that wireless applications have not penetrated the agricultural sector at all. 2-way radios and "push-to-talk" cell phones are two examples. These are wireless tools that are relatively cheap, reliable and very simple to use. For several generations, farmers in countries with large farms have used 2-way radios to communicate with employees. Because farmers already understood the benefits of wireless communications, they were some of the earliest adopters of cell phone technology, especially "push-to-talk" cell phones. These devices gave them the mobility to contact their employees, farm supplier, equipment dealer, extension agent, buying point or spouse from anywhere at anytime. Today, the cell phone is indispensable to farming (Kvien, 2005).

In addition to being cheap, reliable, and simple to use, cell phones have one more important attribute – all brands are compatible. Unfortunately, the same cannot be said for the wireless sensor and control networks which turn switches on and off, check fuel levels or stream video. At the moment, these technologies all work differently, require proprietary software, include components which are expensive and often not compatible and are frequently cumbersome to use. However, that is likely to change because of the rapid pace of development in certain sectors of internet communications (Pocknee, 2005).

Over the past decade, the internet has matured to an extent that it now carries a substantial amount of communications. It is likely that new innovations and developments will only increase reliance on it. One of these innovations is wireless delivery of the internet. The internet is a diverse communications medium that can support voice and video as well as machine-to-machine monitoring and control through wireless networks.

NESPAL – the National Environmentally Sound Production Agriculture Laboratory at the University of Georgia (Pocknee, 2005) and other research groups (McKinion et al., 2004) have been evaluating the use of wireless internet networks for farm applications. These applications show so much promise that the authors predict that during the coming decade, wireless networks will offer the same type of quantum leap forward for farming that GPS provided during the past decade. Internet networks are likely to eclipse the capabilities of all previous forms of distance communication and will provide the communications backbone for farms in the future (Kvien, 2006).

Wireless networks

Wireless networks refer to a standardized set of digital radio technologies that allow computers and other electronic devices to communicate and access the internet without being physically connected via a cable. Thysen et al. (2000), in a keynote address entitled "Agriculture in the Information Society" heralded the potential of the wireless internet stating:

> "In the Network Society, the farmer can connect to the network from any place he wants, by powerful wireless communication links. He can monitor any aspect of the farm, because all farm machinery and farm equipment, even farm animals, are provided with miniature computers and connected to the network; he may install various kinds of sensors at any place he wants and access them at any time; and he may access any data he wants from outside sources."

Table 1 lists some of the more obvious uses of an on-farm wireless network, but it is too early to tell what applications will be most popular. All of the tasks listed in Table 1 can be accomplished with existing wireless solutions but applications are rare. Any new generation wireless solution must show compelling benefits beyond those being offered by current solutions as did the cell phone compared to the 2-way radio.

At the moment, the wireless internet industry is growing at a frenetic pace and new types of networks are being developed and released regularly. These rapid changes are confusing to network professionals let alone a farmer attempting to select the best option for the farm. Although an on-farm network does not need to be connected to the internet, an internet connection can extend the geographic reach of the farmer so that tasks can be performed and monitored from any location. For remote monitoring and control of farm operations using the internet, a transmission speed of 128kbps or better is needed. This usually precludes the use of dial-up internet connections which generally are limited to 56kpbs so other solutions must be sought (McKinion et al., 2004).

The rural internet

Today, it is common to find broadband (high-speed) internet available in small towns. The problem is extending this availability to the farm – what is euphemistically called "bridging the last mile" by the industry. Although there are local government initiatives in many areas which are producing 'wireless clouds' over rural communities (Mascoe and Hook, 2005), individual initiative and creativity is playing an increasingly important role in networking rural communities.

One approach is to use off-the-shelf wireless networking technology to create a broadband link between two sites that are up to several miles apart. A shared broadband connection makes it possible for users who are scattered across a wide area to build a network spanning widely separated sites. For example, a farm house or office that has a high speed connection might agree to share its connection with neighbors. These neighbors could set up a point-to-point wireless link to bring internet access to their home or office. Thus, someone several kilometers away may be linked to the internetvia several intermediate relay points. This can be done at a relative low cost to the users but relies on individuals being willing to share their connections, as well as

Table 1. On-farm needs for which new-generation wireless applications can provide better solutions (Pocknee, 2005).

1. Remote monitoring
- Data from gauges and sensors (soil moisture, pressure, environmental, etc.)
- status of farm gates and building doors (open/close)
- status of irrigation valves
- status of pumping equipment
- live video of operations
- monitoring of greenhouses, livestock enclosures, and storage facilities
- audible or other alarms

2. Remote control
- opening and closing valves & gates
- turning on and off lights, pumps, heaters, etc,
- guiding robotic vehicles

3. Information transfer
- automatic incorporation of environmental data into decision support systems and crop models
- uploading maps to variable rate application equipment
- weather, market, & operational information to remote locations & vehicles
- real-time information such as DGPS correction signals

4. Communication
- text, graphical, voice and video messages can be sent between operators

5. Asset tracking
- position of irrigation systems
- location of farm vehicles
- location of livestock

6. Remote diagnosis
- remotely located technicians and specialists can access, monitor and control on-farm assets with the permission of the local manager

maintaining the wireless equipment and the network (the chain is only as strong as its weakest link).

As stated earlier, broadband internet access is not necessary to establish an on-the-farm wireless network which uses internet communication protocols. Broadband internet access simply allows the farmer (and others with permission) to access the wireless farm network from any point on the planet. The farm network allows the farmer to wirelessly implement all the tasks listed under sections 1-5 in Table 1 and shown graphically in Figure 1. Generally speaking, the farm network can be considered a wireless local area network (WLAN). A WLAN is defined as a network that uses a standardized set of high-frequency radio waves rather than wires to pass information between nodes of the WLAN and carry information such as data, voice and video to a central location on the farm. The IEEE 802.11 standard and modifications to this standard specify the technologies for WLANs. The 802.11b standard – also called Wi-Fi (Wireless Fidelity)

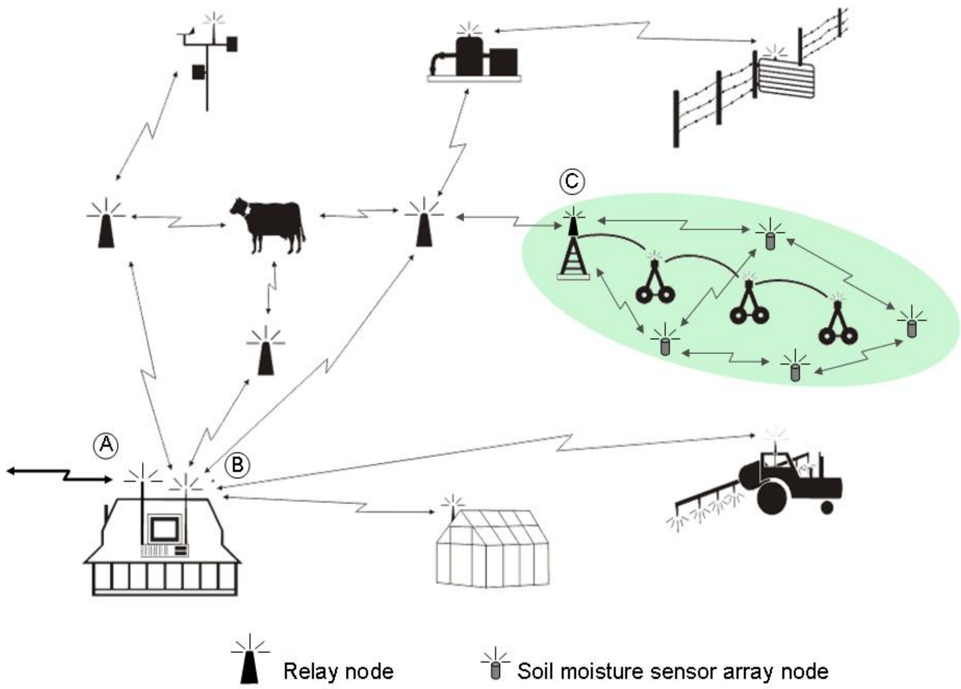

Figure 1. Schematic of a farm showing three nested levels of wireless networks. The first level is the 'wireless cloud' which brings broadband internet to the farm. The farm's gateway to this network is at point (A). The second network is a whole-farm wireless sensor network (WSN) with both monitoring and control nodes. Relay nodes are used to extend coverage throughout the farm. The gateway to this network is at point (B). The final nested network is a WSN dedicated to one field where it is used to monitor the center pivot irrigation system as well as an array of soil moisture sensors. The gateway to this WSN is point (C) which is also a relay node in the whole-farm WSN.

is most commonly used for WLANs. Using repeaters, WLANs can easily cover the area of a large farm.

<u>The farm WLAN of the future</u>

The farm WLAN of the future is likely to consist of a large number of nodes which have sensors and actuators (also known as controllers) to monitor and modify the physical state of the farm (Willig, 2006). The farm WLAN will also have a gateway unit which communicates with other computers via other wired or wireless networks and can provide access to broadband internet. Within the farm WLAN, nodes will communicate wirelessly between themselves and the gateway using radio frequency transceivers, will be energy efficient and will have sufficient computational resources to perform signal processing tasks (Wang, 2006; Willig, 2006; Pottie and Kaiser, 2005). WLANs which are dominated by sensor nodes are also referred to as wireless sensor networks (WSNs).

The great advantage of WSNs is of course that they are wireless. This enables the installation of nodes in locations that would otherwise have been prohibitive because it would be impractical or too expensive to extend communication cables to the sensors. A recent estimate found that typical wiring costs in industrial installations range between USD 130–650 per meter (Sensors Magazine, 2004). It was also estimated that adopting wireless technology may eliminate 20–80% of this cost (Wang, 2006). In agriculture, the advantage of going wireless is obvious to anyone who has installed sensors and cables in a production field and faced the frustration of high cable costs, the labor of installing the cables after planting and removing them prior to harvest, cut or damaged cables from wildlife and farm operations and lightning strikes.

To date, the limitation to going wireless has been expensive, high power radio transmitters which usually require a government license for use of the radio frequency and still require extensive cabling if sensors are multiplexed (Vellidis et al. 2006). Several recent developments in radio frequency (RF) transceiver technology have sharply reduced the cost and energy required for short-distance RF communication and thus enabled the development of WSNs. Not only do these recent developments allow for more efficient RF communication, but the cost reduction has been so dramatic that it allows for WSNs to include a high population of sensor nodes – something very much needed in systems with high variability such as agricultural production. Wang (2006) summarizes available wireless networking standards that are most suited to WSNs with large number of sensor nodes.

WSN node requirements and components

A node may contain sensors, sensors and actuators or just actuators. The sensors may be any transducer or combination of transducers which measure a desired parameter – most typically an environmental parameter such as temperature, soil moisture, flow, humidity, etc. The sensor may also be a video camera. The actuator provides the control function desired and may be a switch that turns a motor on or off, a speaker that provides an audible command or a variety of other devices.

In addition, the node will include analog-to-digital and/or digital-to-analog converters if needed and an on-board micro-controller which runs the application software. The microcontroller reads the sensor data and, after processing and formatting, outputs the data to the onboard wireless transceiver. The microcontroller is also responsible for any control commands directed to the actuator(s). It is important that microcontrollers be rugged, flexible, easily programmable and energy efficient (Willig, 2006).

Perhaps the most important component of the node is the wireless transceiver hereafter referred to as a mote. The mote modulates and transmits and receives and demodulates digital data. Most node designs rely on radio frequency communications in unlicensed bands like the 2.4 GHz industrial, scientific and medical (ISM) band, for which several mote designs are commercially available (Willig, 2006). Energy-consumption is an important parameter in mote selection and there must be a compromise between transmission range and energy consumption.

The power supply provides energy to the node and is frequently a lithium battery. Consequently, node designers attempt to minimize energy consumption in order to reduce maintenance requirements of the nodes. Practical node designs will ensure that a battery will last through the busy growing season. Ongoing research is focusing on creating self-recharging batteries (Sarkar and Adamu, 2003) and other energy scavenging approaches (Roundy et al., 2004) because current recharging techniques such as solar panels add significant cost and maintenance requirements to a node.

Case Studies

Wang et al. (2006) provide a thorough review of applications of wireless sensors and networks in agriculture and food production including a discussion of precision agriculture applications. Of particular interest is a project recently conducted in Mississippi, USA, where a team of researchers established a whole-farm WLAN which connected cotton pickers, spray equipment, variable rate application equipment and hand-held personal digital assistant computers in the field, allowing for rapid bi-directional movement of data and information (McKinion et al., 2004). Rather than list a long series of applications, three case studies illustrating the use of wireless network applications in agricultural environments will be examined.

<u>A WSN for monitoring soil moisture and temperature</u>

Radio frequency identification, or RFID, is a generic term for technologies that use radio waves to transmit key information over short distances. RFID technology consists of two critical components – a RFID tag or transponder and a RFID reader. A RFID tag consists of a microchip with memory and an antenna coil. Some RFID tags are microscopic -- thinner than paper and only 0.3 mm in diameter. The tag is dormant until it receives a radio signal from the RFID reader. Once the tag receives the signal from the reader, it wakes up and responds by transmitting its unique ID code and other data stored in its memory back to the reader. The transmitted information generally describes the identity, location and/or condition of physical objects as varied as cows, pets, shipping containers, people, surgical instruments, documents, automobiles using EZPass to drive through a toll booth and countless other items.

University researchers and private companies are beginning to integrate sensors that detect and record temperature, movement, radiation and even soil moisture with RFID tags which provide the wireless connection to gateway. In these applications, a microcontroller collects data from the sensors and then writes the information to the memory of a read/write RFID tag. The tag then transmits the data to the reader or gateway and ultimately the user when queried. Within the near future, RFID tags can be expected to not only track items moving through the supply chain but to also record product temperature during transit or storage, presence of pathogenic bacteria in the shipment, or even if someone has injected a biological agent into food.

At the University of Georgia, active read/write RFID tags have been integrated with soil moisture and temperature sensors. The sensors are wired into a small circuit board which processes the sensor information and writes the data to the memory of the RFID tag. Nodes consisting of two or three soil moisture sensors, two thermocouples for reading soil and canopy air temperature, the small circuit board and a RFID tag are installed at many locations within a field to monitor soil moisture and temperatures as shown in Figure 1. The tag memory stores data collected over a 24-hour period. The reader, located at a central location in the field, receives information sent by the tags at pre-determined intervals. The soil moisture data (Figure 2) and temperature data are then downloaded by the user (researcher or grower) from the reader via a whole-farm WSN to determine whether irrigation is needed as indicated. As shown in Figure 1, several levels of networking are combined.

After three years of testing, the system has proved reliable and easy to use. Its main advantage over other wireless soil moisture monitoring systems is that, because RFID is

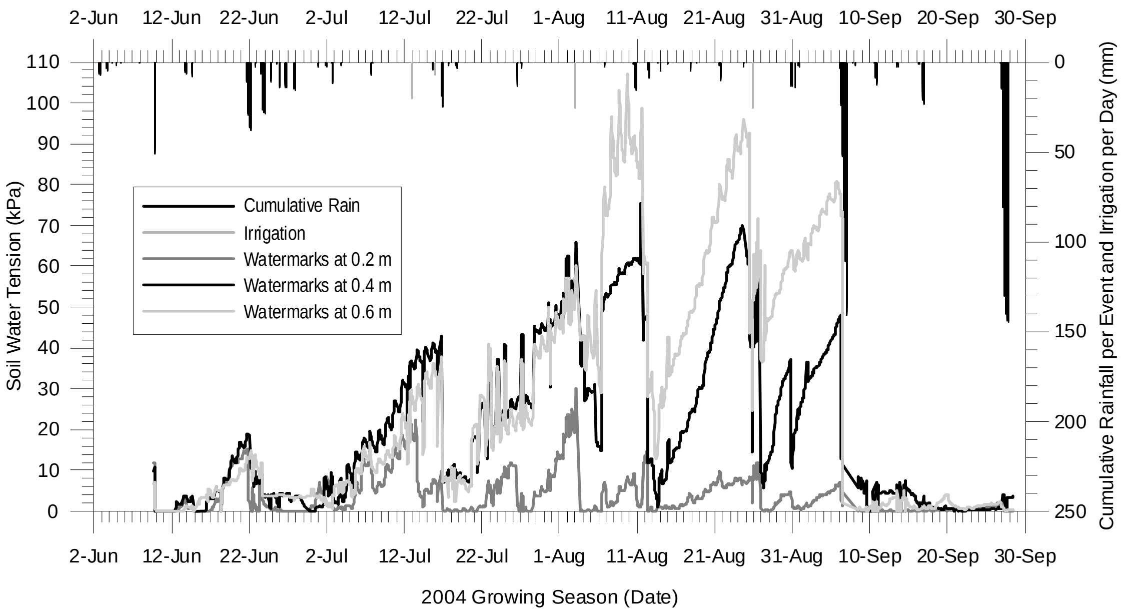

Figure 2. Soil water tension recorded by Watermark® granular resistive-type soil moisture sensors interfaced with an RFID transponder within a WSN. The data are an average of soil water tensions recorded at three nodes with each node consisting of sensors at three depths (Vellidis et al., 2007).

cheap, the cost of a node is less than USD100 compared to USD700 or more for conventional wireless systems. This price allows a much higher density of sensors in the field providing better information on the status of the crop – an important parameter for properly scheduling irrigation especially when using variable rate irrigation (VRI) systems.

Network cameras – the most flexible farm sensor?

Of all the sensors that can be used with a wireless network, perhaps the most practical and flexible is a network camera (Macheski-Preston and Pocknee, 2005). Even the most basic of network cameras can be used for many different applications. One of the most used applications is for monitoring – in the same way as closed circuit video cameras are used. Fuel tanks, chemical stores, production lines, pivots and even fields can all be visually monitored and recorded if necessary over an ethernet-based network. If the camera network is connected to the internet, the cameras can be viewed from anywhere in the world. Many cameras also transmit audio. More sophisticated cameras can be incorporated into nodes with actuators allowing control of electrical devices at the camera location. Unlike a webcam, which requires a computer, a network camera is independent. It just needs a source of power and a network connection. There are an expanding number of network cameras on the market ranging in price from USD 50 to more than USD 1000.

A successful application of a wireless network has been at Lewis Taylor Farms, a very large vegetable farm in southern Georgia, USA. The owner was interested in using cameras to monitor vulnerable assets such as fuel and fertilizer storage tanks as well as to monitor the various vegetable packing houses on the farm. Monitoring of the vegetable packing houses was both a security and a food quality issue. During peak periods, there can be up to 100 workers sorting, cleaning, grading, packing and loading produce. A cost estimate for a traditional closed-circuit video surveillance system was

Figure 3. Images from nine internet cameras used to monitor the packing house and other facilities at Lewis Taylor Farms (left) and an example of the cameras used at the facility (right).

prohibitively expensive because of the large distances between the surveillance locations and the numerous surveillance points within each location.

The main office already had a broadband internet connection provided by a commercial service provider so work focused on building the whole-farm wireless network. After considerable experimentation, a wireless network was established to link the main office to the packing houses and fuel and fertilizer storage tanks. Because the cameras required AC power, the camera nodes within buildings were also wired for data transmission even though the cameras themselves were capable of wireless data transmission. In the end, this was a wise decision because the within-building wired network was essentially maintenance-free and the cost of adding ethernet wiring was not much higher than the cost of installing the AC wiring.

Dedicated software was purchased to allow the owner to simultaneously view and control up to 16 different cameras (Figure 3). A dedicated hard drive was also purchased to digitally store the camera images which, using the software, can be retrieved for later viewing. The owner is heavily involved in a variety of local, national and international activities with production units in South, Central, and North America and is considering installing similar systems at all his production sites. This system allows him the freedom to manage his operations regardless of his location.

Despite the apparent simplicity of the method described above, this application was fraught with problems. The large number of cameras initially saturated the bandwidth. To solve this problem, the resolution required of cameras was optimized and a second access point operating on another channel was established thus splitting the cameras between the two access points. This greatly increased the reliability and frame rate of the cameras. Another issue was the management of user-names, passwords, IP addresses and communication ports as well as assimilating multiple camera models from multiple manufacturers. These problems were mostly solved by purchasing software designed to control internet cameras rather than using free shareware.

<u>The Mitchell Farm – tomorrow's farm today</u>

The Mitchell Farm is a 1000 ha row-crop operation in Iowa, USA, growing corn and. The farm consistently uses the latest technologies available in production agriculture.

For example, the farm was the first in the Midwestern USA to use autosteer guidance as well as a number of other technologies associated with precision agriculture. But what really sets the farm apart is the whole-farm high-speed wireless network that was established in 2002, spurred by the investment in the autosteer technology. "We realized we could use the autosteer RTK guidance system's radios to simultaneously transmit data for a computer network – thanks to their multiple ports, seamless roaming capability and built-in internet enabling features," Clay says (Perry, 2005).

The wireless network infrastructure consists of both 2.4 GHz and 900 MHz segments, a primary 45 m network tower, a repeater unit on a 27 m grain bin, and a mobile repeater mounted on a pickup truck. Operating at two radio frequencies provides complete coverage across the entire farm. Devices communicating over the wireless network include a desktop computer in the farm office, laptop computers in tractors, combine and trucks, and programmable logic controllers (PLC). The network provides high-speed internet service, a mechanism for remote machine monitoring and control, and also provides two types of GPS correction signals for their vehicle guidance. Having the network farm-wide has changed tractor and combine cabs into mobile offices. Now the internet can be used to send/receive email, check current market conditions, catch up on the news, and even order parts - all from the cab without stopping for any appreciable amount of time. Other uses for the network have included accessing yield maps and other data from the office computer, transmitting digital pictures of weeds or insects found in fields to their chemical dealer for identification, monitoring weather conditions, downloading aerial images of the farm and storing/accessing autosteer configuration data (Perry, 2005).

The PLCs that communicate on the wireless network are part of an automated grain storage system that was developed on-farm. The system can control air pressure, motor currents, temperatures and running time. A laptop computer can be used anywhere on the wireless network to communicate with the PLCs and monitor how much grain is in a bin, monitor drying progress, move grain from bin to bin, generate moisture profiles, etc. Without such a system, extra staff would be required to monitor the grain bins. On the Mitchell farm, wireless networking has become as essential as cell phones and business band radios. The network is owned by the farm and so the wireless service is free, it is always on and is very fast (Perry, 2005).

Discussion

Precision agriculture and precision livestock farming are disciplines driven by information. WLANs in combination with new generations of smart sensors which transmit data only when human intervention is required offer the farmer the potential of unlimited access to information at all times as well as the ability to respond immediately to situations that require attention. In this lies the promise of increased efficiencies.

As shown on the Mitchell Farm, the presence of a WLAN also enables many other technologies and allows the farmer to multi-task. The Mitchells have even gone as far as to add a small office to the cab of their grain combine so that while the machine is harvesting in autosteer mode, they can use the WLAN to monitor and adjust the conditions of their grain bins so that energy is saved and corn is dried to optimal conditions. At the same time, they check on grain prices to determine if the dried grain should be put in storage or sold, evaluate the status of other farm operations, or call up yield maps from previous years to compare to the current yield map. The ability to multi-task may lead to an increase in efficiency, but perhaps also an increase in stress.

Unbridled enthusiasm for the potential of wireless technologies must be tempered by the fact that this is an emerging and consequently rapidly changing technology. Inherent to this stage of development of any technology are many obstacles to adoption (as encountered in precision agriculture). Some of these obstacles are:

- With so many options to chose from, what is the best WLAN?
- Early adopters often encounter so many problems that they abandon the technology and adversely influence potential new users.
- Without smart sensors, data generated from WSNs can become overwhelming and remain unused.
- Existing IT infrastructure may not accommodate the growth of wireless networks.
- If the farm WLAN is connected to the internet, security is an issue.
- Long-lasting and self-charging power supplies are needed for sensors and actuators to truly take advantage of the potential of WSNs.
- Reliability of the network, sensors, and actuators.
- Lack of technical support in rural areas.

Conclusions

Although the wireless farm of the future offers great potential for improving efficiencies, it will not materialize without an equal quantum leap in the ability of farmers to understand electronics. Even the most robust wireless systems will require regular maintenance, repair and upgrades. As learnt from a decade of implementing precision agriculture, adding technology to the farm may reduce the number of people required but dramatically increases the needed educational and competence level of the remaining workers. There will be a market for network and sensor specialists and other technologists in rural areas which may reverse the century-long trend of the brightest minds migrating from the countryside to the city.

We are convinced that during the coming decade, wireless networks will offer the same type of quantum leap forward for farming that GPS provided during the past decade. Internet networks will eclipse all previous forms of distance communication and will provide the communications backbone for farms in the future.

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