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Implementing Intelligent Monitoring Techniques in Agriculture Using Wireless Sensor Networks

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Abstract: More than two-thirds of freshwater consumed worldwide are used for irrigation, and large quantities of freshwater can be saved by improving the efficiency of irrigation systems. Irrigation control systems deployed in agriculture can substantially be enhanced by implementing intelligent monitoring techniques enabling automated sensing and continuous analyses of actual soil parameters. Automatically scheduling irrigation events based on soil moisture measurements has been proven an effective means to reduce freshwater consumption and irrigation costs, while maximizing the crop yield. Focusing on decentralized autonomous soil moisture monitoring, this paper presents the design, the implementation, and the validation of a low-cost remote monitoring system for agricultural ecosystems. The prototype monitoring system consists of a number of intelligent wireless sensor nodes that are distributed in the observed environment. The sensor nodes are connected to an Internet-enabled computer system, which is installed in an agriculture farm for disseminating relevant soil information and providing remote access to the monitoring system. Autonomous software programs, labeled "mobile software agents", are embedded into the wireless sensor nodes to continuously analyze the soil parameters and to automatically trigger irrigation events based on the actual soil conditions and on weather data integrated from external sources.

Key Words: Agricultural ecosystem monitoring; agro geo informatics; irrigation control; smart sensing; wireless sensor networks; multi-agent technology.

INTRODUCTION

Wireless sensor network (WSN) of spatially distributed autonomous sensors to monitor physical or environmental conditions such as temperature, air humidity, pH value, CO_2 concentration etc. and to cooperatively pass their data through the network to a main location. Recently developed networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – with a several hundreds or even thousands, where each node is connected at least to one (or sometimes several) sensor(s). Each such sensor network node has typically several parts: a radio trans receiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to several hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communication bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique in between hops of the network may be routing or flooding.

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 during the last decade, that had 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.

RELATED WORK

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. 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 can not be meant 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 a 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.

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 0at any time; and he may access any data he wants from outside sources."

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.

EXISTING WORK

Main reasons for the global water crisis – besides population growth, urbanization, and climate change – are excessive water use, poor management, and inadequate irrigation. According to the United Nations World Water Development Report, 70% of freshwater worldwide is used for irrigation. Conventional irrigation systems usually work on the principle of timer-based irrigation. Timer-based irrigation controllers, incorporated into an irrigation systems, are deployed to trigger irrigation events using mechanical or electromechanical timers. However, timer-based systems possess several disadvantages because actual soil and weather conditions are not considered. Consequently, the amount of applied water does usually not match the requirements of the irrigated crop, and either too much or too little water is used for irrigation. Recent studies have unveiled that less than 40% of applied water is used by the irrigated crop effectively. Furthermore, it is well known that poorly managed irrigation systems not only contribute to water scarcity, but can also lead to significant soil damage caused by draining (due to water shortage) or leaching (due to excessive water application) entailing a further reduction in crop yield.

To overcome the problems caused by inadequate and expensive irrigation, “smart” irrigation controllers have been proposed as an alternative to conventional timer-based irrigation controllers. Smart irrigation controllers, such as weather- or soil moisture-based devices, are able to automatically trigger irrigation events depending on actual site conditions. Soil moisture-based controllers, for example, trigger irrigation events based on the soil moisture content in the root zone of the crop. Ensuring a soil moisture level between the field capacity of the soil and the wilting point of the crop, soil moisture-based controllers typically determine the water requirements by comparing the soil moisture measurements with pre-defined threshold values. Although smart irrigation controllers are capable of timely initiating irrigation events, there are several limitations associated with smart controllers available in the market: Many smart irrigation controllers lack the ability of automatically adjusting the irrigation run times, i.e. the quantity of applied water, based on real-time soil moisture measurements; rather, a preset quantity of water is applied for an irrigation event independently from the actual soil conditions. In consequence, even well designed and well-managed state-of-the-art sprinkler irrigation systems achieve maximum irrigation application efficiencies between 20% and 75%. Apart from that, significant installation and maintenance costs due to wiring of the controllers arise, with at least US$ 130 per meter according to recent studies.

With the advancements in wireless communications and microcontroller technologies, wireless sensor networks are deployed in agriculture to overcome the functional limitations and the high costs associated with conventional (cable-based) irrigation controllers. Measuring relevant parameters from the monitored environment, wireless sensor nodes are capable of hosting intelligent software programs facilitating efficient, decentralized and low-cost irrigation control strategies. Besides the flexible and rapid deployment of wireless sensor networks, a significant reduction in installation and maintenance costs of 20-80% can be achieved as compared to cable-based systems. Nevertheless, while wireless sensor networks are used for monitoring in related disciplines since many years, the deployment of wireless monitoring systems in agriculture, supporting the new concept of “precision agriculture”, is still rare.

Although wireless sensor networks deployed for irrigation control in agriculture have been proven cost- and resource efficient with water savings up to 60%, most systems do not integrate automated decision support functionalities providing optimum irrigation scheduling. Instead of individually performing data acquisition, data analysis, data aggregation and decision making directly on the sensor nodes, the vast majority of systems is designed solely for data acquisition and transmission of data sets, to a server systems connected. Requiring extensive amounts of data to be wirelessly transmitted, sensor data is usually collected by the wireless sensor nodes and then sent to a central server for further processing; data analysis and the decision making need to be conducted by human individuals manually. In this study, an intelligent remote monitoring system, composed of a number of wireless sensor nodes and a computer system located on site, is proposed for irrigation control in agricultural ecosystems. Data acquisition, data analysis, data aggregation and decision making are performed directly on the sensor nodes, and real time soil moisture measurements as well as actual weather data are used to schedule irrigation events autonomously.

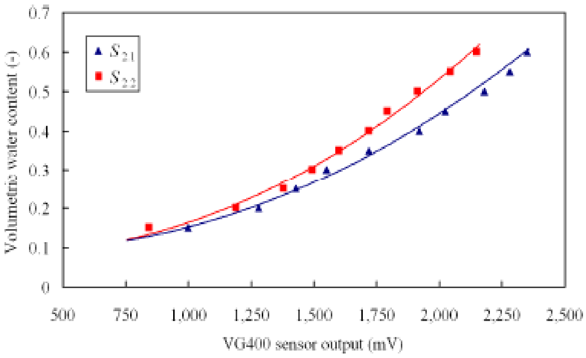
FIELD VALIDATION TESTS

Serving as a proof the concept of the newly proposed agent based monitoring approach, field validation tests are devised. The validation tests are also intended to study the real-time capabilities and the reliability of the mobile agents.

System calibration and test setup

To achieve a high accuracy of the wireless monitoring system, soil moisture sensors, while being attached to the wireless sensor nodes, are calibrated soil-specifically. In a calibration routine conducted prior to the field validation tests in the laboratory, different soil samples have been taken from the area to be monitored. The soil samples have been dried and weighted, and defined amounts of water have been added. Exemplarily, the calibration curves constructed for two soil moisture sensors. These curves are used during the validation tests by mobile software agents to automatically convert the raw sensor readings (i.e. sensor output voltage) into corresponding estimates of volumetric water content.

After calibration, the prototype system is installed in the field to monitor 5.0 m × 2.5 m test area primarily to test the capabilities of the embedded mobile agents with respect to performing cooperative real-time diagnoses of the soil moisture conditions and reacting appropriately of changing site conditions. The area is divided into two monitoring regions. In each region, one wireless sensor node is installed, hosting the mobile agents as described earlier. The wireless sensor nodes (labeled S1 and S2) are connected to the on-site computer, a laptop computer located next to the test area, through the base station. Each wireless sensor node is interfaced with two soil moisture sensors and includes one temperature sensor. The soil moisture sensors are placed at a soil depth of 30 cm representing a typical root zone of a crop. Modified impact sprinklers (I1 and I2) are installed in the middle of each region.



Calibration curves constructed for soil moisture sensor S2.1 and S2.2 when being attached to sensor node S2.

AUTONOMOUS SOIL MOISTURE MONITORING

A relatively simple but efficient test the procedure is applied to validate the capability of mobile agents to cooperatively assess the varying of soil moisture distributions and to timely react on it. The test procedure is carried out in region 2 of the observed area. First, the range of ideal volumetric water content in the root zone of region 2 is pre-defined as $0.1 \leq \theta R2 \leq 0.5$. These threshold values are stored in the monitoring system. As soon as the wireless sensor nodes and the mobile agents are launched, the control agent of wireless sensor node S2 starts analyzing the actual volumetric water content of region 2. To this end, the controller agent requests measurements from the soil moisture sensor agent responsible for the soil moisture sensors S2.1 and S2.2. Averaging the measurements of S2.1 and S2.2, a volumetric water content of $\theta = 0.09$ is determined in region 2, which is slightly below the defined threshold value. The averaged values are periodically sent by the controller agent to the on-site computer, where all data sets are stored being remotely available to authorized human individuals.

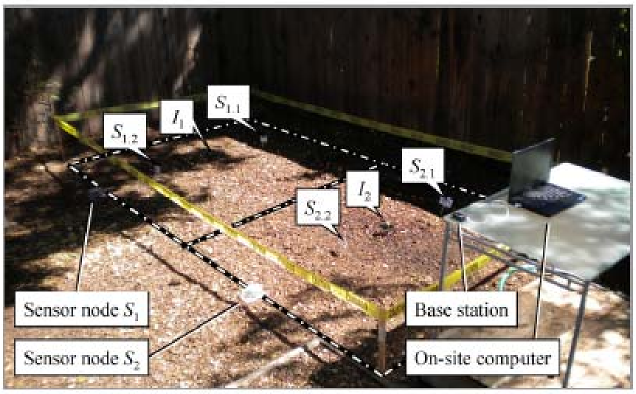


Figure. Field validation tests of the autonomous monitoring system.

CONCLUSION

In this paper, preliminary results have been presented illustrating the design, the implementation and the validation of a low-cost wireless monitoring system for agricultural ecosystems. The prototype monitoring system consists of a number of intelligent wireless sensor nodes, which are connected to an Internet-enabled computer system installed on site to store and disseminate relevant soil information and to provide remote access to the monitoring system. Specifically, intelligent software programs ("mobile software agents") have been embedded into the wireless sensor nodes enabling (i) autonomous communications among the sensor nodes, (ii)cooperative decision making for scheduling irrigation events in real time, (iii) dynamic adaptations to changing environmental conditions, and (iv) remote access to relevant soil information.

Field validation tests have corroborated that the concept of embedding mobile software agents into wireless sensor nodes can largely enhance the efficiency and the reliability of monitoring systems deployed in agriculture. Focusing on soil moisture monitoring, it has been shown that mobile agents, performing data acquisition, data analysis, data aggregation and decision making directly on the nodes, are able to respond in a timely manner to changes in the soil and to precisely schedule irrigation events, which results in a reduction of freshwater consumption and lowered irrigation costs.

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