Next-Generation Monitoring and Control Hardware Development

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Abstract. *Wireless Sensor Network (WSNs) systems form an invaluable tool in agriculture. Currently these systems are good at reporting and logging data. This work extends WSN's for the next generation of systems. The next generation needs to have a nimble user interface capable of viewing and analyzing the data in real time. To extend the WSN capability the next step is adding direct irrigation control from the WSN nodes.*

This work focuses on the development of a WSN system that gives users the ability to get actionable results from the data, as well as monitor and control irrigation from a central location. A node capable of controlling irrigation was developed as well as a secure protocol to safely communicate between the basestation and the node. Other issues such as system security, graphical tools, and data management are discussed. This system is deployed at over a dozen sites and is constantly evolving based on user feedback.

Keywords. WSN, wireless sensor networks, irrigation, control, intelligent, hardware, nodes

Introduction

Wireless Sensor Network's (WSN's) for agriculture are becoming more popular as the systems become more mature and can provide financial benefit [Chappell & van Iersel, 2012; Majsztrik, Lichtenberg & Lea-Cox, 2012]. These systems provide real-time data that is important for making critical irrigation decisions [Lea-Cox. et. al. 2009]. Making every aspect of the WSN work reliably is important for wide scale adoption. This work presents some of the design decisions for this system as well as the WSN system that was produced. The node was developed by Decagon Devices Inc. and the user interface and basestation was developed at Carnegie Mellon University.

Wireless Measurement and Control Node

Within a WSN system the node is the device that collects data from the sensors and transmits the data to the basestation (discussed in the section below).

Hardware

Two nodes (Fig. 1) were developed for this project by Decagon Devices Inc. For reliability purposes the design was based on the existing Decagon Em50R node. The first node developed with irrigation control capability was the nR5. The nR5 is capable of switching a 24VAC solenoid valve that is standard in many irrigation applications. Based on feedback from growers, Decagon also produced the nR5-DC node that is capable of controlling DC latching solenoids. These new latching solenoid valves do not require external 24VAC power to operate; this decreases the expense and labor of setting up an irrigation block while also making the irrigation blocks more flexible. The nR5-DC uses the internal power supply to generate the positive and negative voltage necessary to switch the DC latching solenoids. Both nodes maintain the Em50R nodes ability to read up to 5 sensors [van Iersel, 2012]. The nodes also have an integrated circuit to detect if the voltage is correct for irrigation to occur. This provides a good first order alert to growers that an error exists in their irrigation system.

Fig 1. Left: Inside of an nR5-DC node used for irrigation control. Solenoid wires can be seen to the right of the batteries [Lea-Cox & Belayneh, 2012]. Right: External image of a node [Decagon, 2012].

The nodes use a 900MHz ISM radio which allows for better penetration through crops and for an increased range compared to higher frequency radios such as the popular 2.4GHz ISM bands. There are also user configurable channels so that multiple WSN systems can be used in close proximity without interfering with each other.

Node Firmware

The node software is responsible for reading data from the sensors, controlling irrigation, and transmitting the measurement and status data to the basestation. The nodes use a binary protocol that was developed for this project. Using a binary based protocol allows more data to be transmitted per packet as opposed to an ASCII based protocol. The data packet size is optimized for efficient transmission based on the radio being used in the node. Minimizing data transmissions helps increase the battery life in the node. This protocol allows for two way data transmission so that users can adjust settings from the basestation and do not need to physically go to the node.

To insure integrity of the transmitted data the node uses cyclic redundancy check (CRC) codes in every packet. The basestation software then uses the same algorithm to check that the packet is valid by re-computing the CRC and comparing it to the transmitted CRC code. The system employs a confirmed delivery protocol to verify that the basestation received the data. After every data transmission the node listens for a confirmation from the base that includes the packets CRC and a sequence id. The node will repeat this up to 10 times in an attempt to transmit the data to the basestation. The node and basestation software use this single confirmation step when transferring measurement and status data and when responding to simple commands. For manual irrigation commands, a double confirmation approach is used to prevent accidental over-irrigation. When a manual irrigation command is sent from the basestation to the node a special confirmation packet is sent back to the basestation, in response the basestation confirms that it received the special confirmation packet.

Every 24 hours the node also transmits all of its configuration and status information to the basestation to give the system user the ability to monitor the health of the wireless network. In small embedded systems keeping track of accurate time is often a problem. In this system every time the base sends a confirmation packet to the nodes it has the current time in the packet that the nodes can then use to correct its internal clock.

In order to save battery power, the node powers down the radio immediately after it receives a confirmation packet from the basestation software. If the basestation needs to send additional data to the node, it sets a flag in the confirmation packet to instruct the node to stay awake for a short interval and listen for incoming packets.

Controlling irrigation with sensor measurement is not a trivial task. This system was designed with error detection and safe failure modes designed to protect a growing crop. Before any irrigation event occurs that is based on a sensor measurement, the node verifies that the sensor value is within a pre-defined range of valid values. If the average of several sensors are used for control decisions, only sensors reporting valid values are used in the average. This type of system catches many of the observed sensor problems; however, there is opportunity for improvements in this area. For example if a soil moisture sensor is only partially inserted into the ground it might return a valid value for a working sensor and trigger an irrigation event that is not desired since the moisture measurement would be low.

The nodes report general irrigation status and error messages to the basestation during each scheduled irrigation event. Examples of reported messages can be as simple as what it is using as a time source to status about why an irrigation event failed.

Basestation

Hardware

The basestation in this system is an inexpensive netbook (laptop) computer and a radio module. A netbook was chosen since it allowed for easier debugging in earlier systems. While the original plan was to switch to an embedded computer with no display once the system had matured, users liked having the netbook as part of the system. Most of the systems are operated remotely over the internet however when users are on site and want to quickly check something the netbook with its integrated screen is useful. Also many agricultural sites are in remote locations and internet can be unreliable, by using the netbook a user can get direct access to the system.

The basestation radio connects to the netbook over USB. The radio module consists of the antenna, the radio and a weather resistant enclosure. The communications channel in the radio can be changed to match the channel of the nodes radio in order to successfully communicate with different networks.

Fig 2. Basestation radio module

Basestation Software

The basestation computer uses an SQLite3 database for storing all of the node sensor data as well as for all node settings. SQLite3 was chosen since it is file based and has fast query times. SQLite3 is slower than some other database types for inserts; however, there are relatively few inserts and this database needs to have fast queries for when it is pulling lots of sensor data for tasks such as generating charts. Since these queries can be very large it is important to carefully construct queries so that only the necessary data is selected.

The user interface [Kohanbash et. al. 2012b] is written in Ruby on Rails. This is a web based interface that can be accessed over the internet and is tied in directly to the database. The user interface is password protected to prevent unauthorized users from entering the system. Also within this system there are various access levels ranging from only being able to view data, to being able to control irrigation, to full administrator access.

The user interface (Fig. 3) is designed to let users view data at a glance while also giving the ability to delve into the data for further analysis. This interface is a central location where users can also configure node settings (Fig. 4) and irrigation parameters. This saves the user from having to go to each node and manually make changes. The interface is also able to issue alerts so that growers can be made aware of conditions based on sensor data or irrigation as they occur with emails or text message notification.

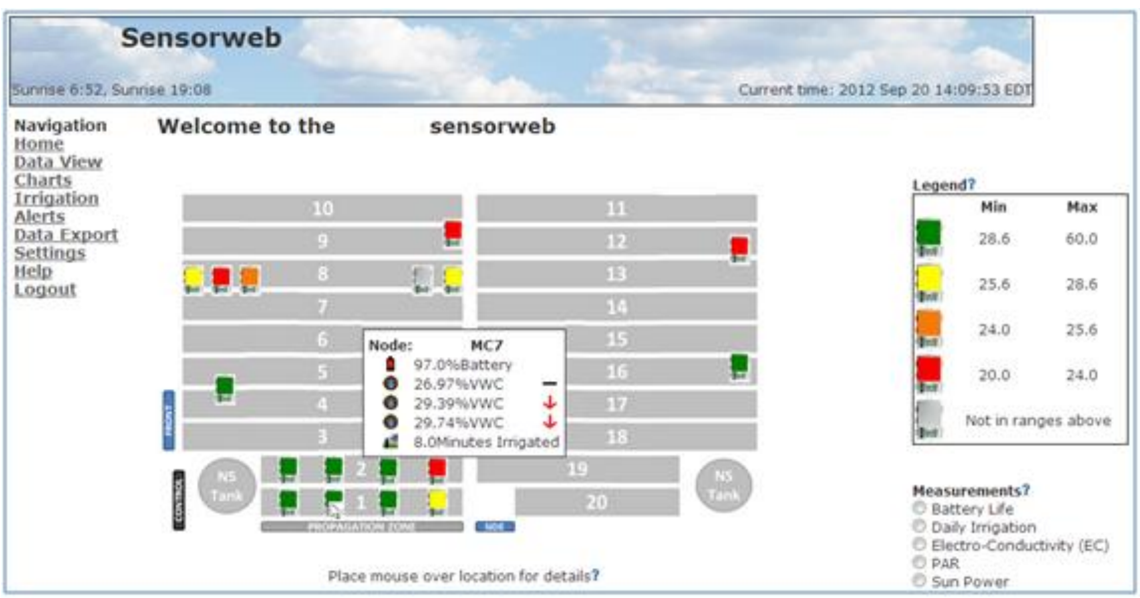

Fig 3. Spatial view showing data and color coded nodes.

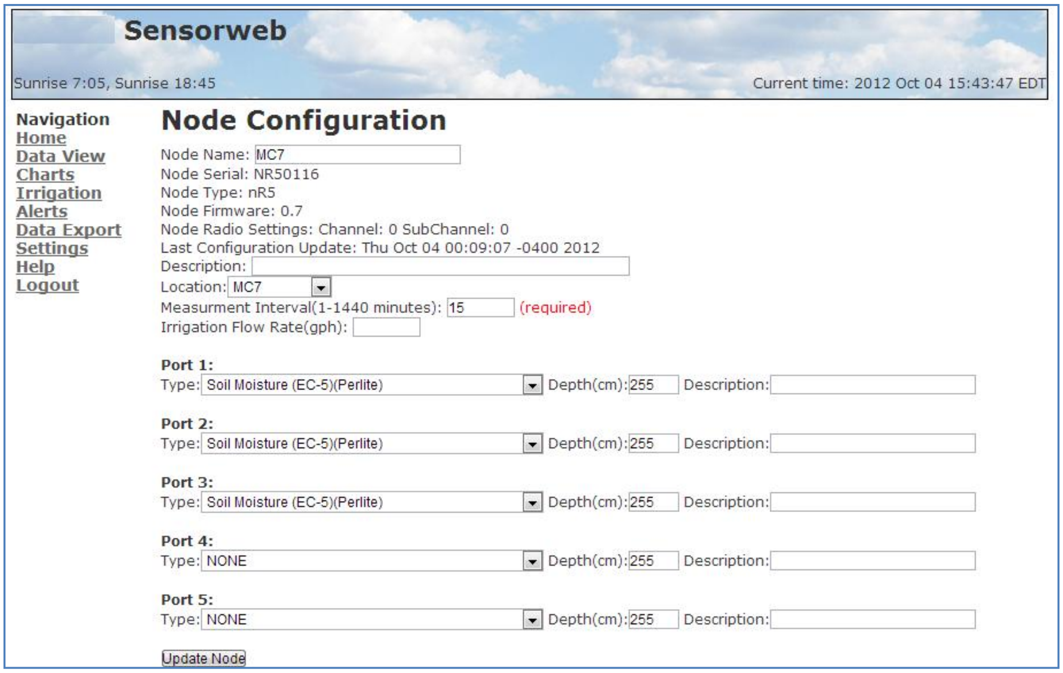

Fig 4. User interface page for configuring node settings. Irrigation parameters are configured on a separate irrigation page.

Node Reliability & Deployments

This system has been running at over a dozen agricultural sites (Fig. 5) over the past few years with new sites continuing to be added [Chappell & van Iersel, 2012]. The system can be setup out of the box without engineering support and runs continuously without the need of constant system rebooting. The nodes have a long battery life that minimizes direct user to node contact.

Fig 5. Map showing location of Sensorweb sites (Image of the USA is from Wikipedia).

Conclusions

Wireless Sensor Networks are proving themselves to be valuable within agricultural environments [Kohanbash et. al. 2012b]. By creating reliable systems with features such as irrigation control and the ability to have an actionable outputs [Kim, 2012] these systems continue to grow. This work demonstrates a system that is easy to setup, easy to use, and reliable. This system is actively being used by growers and researchers in a variety of environments including green houses, nurseries, green roofs, and orchards.

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