Precision Irrigation in Landscapes by Wireless Network
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Introduction

Irrigation control is important since a significant amount of California's available water is used for turfgrass and ornamentals in landscapes. Studies have shown that optimizing water delivery can conserve water and prevent run-off. Many commercial controllers have been developed in order to optimize water delivery by using reference evapotranspiration. These systems can reduce over-watering, but they only address the scheduling aspect of irrigation management and do not help with problems such as varying soil types, elevation, and diverse water requirements for plants in a single landscape. When a large area is uniformly irrigated, each plant may be over-watered or under-watered depending on its species, size, and the water holding capacity and drainage of the local soil. To provide different amounts of water to different regions of the landscape, additional valves, control wires, and irrigation pipe are needed. This can be expensive and time-consuming to install and maintain. Irrigation hardware could be improved by removing the need for power and control wires. They could then be installed in any location with greater ease. Also, intelligent valve controllers could interface with sensors to measure water pressure and soil moisture to further improve evapotranspiration-based irrigation scheduling.

A number of commercial equipment companies have developed irrigation systems such as battery-powered, programmable valve controllers (RainBird, Toro, Netafim, L.R. Nelson Corp.), and valve controllers with wireless communication (Hunter, Rainbird) that alleviate the need for control and power wires. The battery powered systems require yearly replacement of the internal battery, which may be costly and time consuming. There are solar-powered irrigation controllers that do not require external power, but they are expensive and control only a limited number of wired valves (DIG Corp.). Valve controllers with wireless communication usually require the operator to be within a certain range with a handheld programmer in order to modify the controller schedule. A golf course rotor sprinkler was developed that uses a small solar panel to recharge the internal battery and allows wireless programming from a central irrigation controller through a paging subscription service (Rainbird). The disadvantages of this system are that a subscription service is required for the central controller to communicate with the sprinklers and there is no provision for sensor feedback.

Objectives

We are developing a wireless valve network capable of water control through each landscape sprinkler or group of sprinklers. Valve schedules will be different in order to match differing water and fertilizer requirements. This will improve overall landscape health and reduce water waste and fertilizer runoff. Individual schedules could easily be changed to accommodate plant growth and replacement, and seasonal changes. Using pressure sensors, it will be possible to improve water application accuracy over that of fixed-duration irrigation. An added benefit is that these sensors will provide information to automatically detect problems such as leaks and sprinkler head clogging or deterioration. The specific objectives of this two-year project are to

(1) design an intelligent valve controller capable of low-power, wireless communication,
(2) design an energy management system to allow stand-alone operation of each valve controller,
(3) develop a communication network to link the valve controllers with a central field controller, and
(4) develop control strategies for applying water and detecting faults.

Discussion

Overview

Wireless communication will be provided using a mesh network (Figure 1). Mesh networking allows messages to pass from one node to any other node by routing them through nodes in-between. This technique allows increased network range without using high power radios. Another advantage is redundancy. A failed node does not disable the entire network since multiple routing paths exist between nodes. The operator enters irrigation schedules on the central field controller and they are distributed to individual nodes in the network. The optional master computer is a personal computer that can provide a graphical interface, but is not required to operate the system.

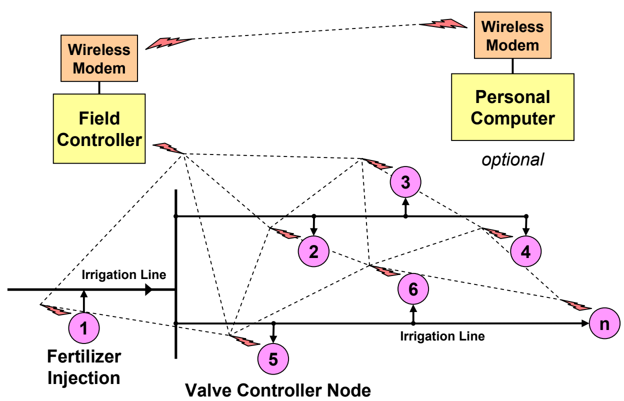

Figure 1. Layout of mesh network for wireless valve control.

Hardware

At the beginning of this project we were using a 2.4 GHz wireless module (Moteiv Corporation, San Francisco, CA, USA) for our valve controller design. A 900 MHz low-power wireless module (Crossbow Technology, San Jose, CA, USA) was adopted in early 2007 to replace those from Moteiv (Figure 2). These modules were selected because the mesh networking software is more robust and the company is interested in developing products for agricultural monitoring and control, thus providing a good opportunity for collaboration and increased likelihood of future commercialization. The wireless module, along with a solar panel, battery, and valve switching circuitry, are connected to a prototype board from Crossbow Technology (Figure 3). The components are housed in a clamshell-style polycarbonate enclosure. The valve controllers have been used to operate 1-inch and 1/8-inch latching valves (Figure 4). A field controller contains a keypad to allow entry of schedules and manual operation of the remote valves, and a liquid crystal display (LCD) for viewing status information (Figure 5).

Figure 2. Valve controller design.

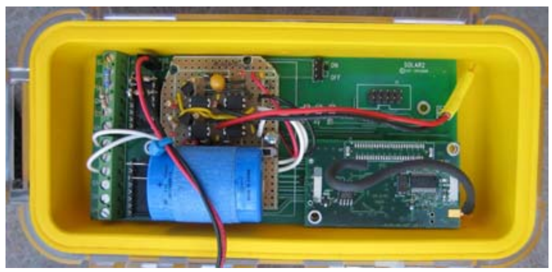

Figure 3. Valve controller design showing circuit components.

Figure 4. Latching solenoid valves with 1/8" or 1" ports for irrigation/fertigation control.

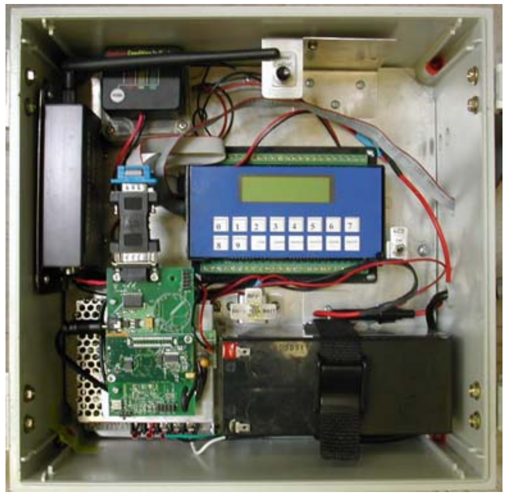

Figure 5. Field controller with embedded controller and wireless module.

Wireless communication

When powered, the nodes automatically begin the process of forming a mesh network. This network allows messages to be passed from node to node in order to improve communication range and reliability. Commands (e.g., open or close valve) entered on the field controller keypad are transmitted to a valve controller with a particular address. The receiving valve controller executes the command provided in the message and then transmits an acknowledgement back to the field controller. In our tests, each node properly opened or closed the connected latching valve using an 80 ms pulse from the battery (2 A peak current). This communication link will also be used to send schedules and receive sensor data.

Maximum one-hop radio range was tested under several different conditions. The wireless nodes were tested with 1/4-wave whip antennas (included with the wireless modules) and 1/2-wave dipole antennas. When using the whip antennas, nodes were tested alone and enclosed in the polycarbonate enclosure (requiring the antenna to be bent). The dipole antenna was mounted on the exterior of an enclosure. The nodes were tested under visual line-of-sight conditions (VLOS, open field) and obstructed conditions (young peach orchard) with the nodes on the ground or elevated on a non-metallic support above ground level. For each case, two or more tests were completed. The results (Table 1) show that range varied greatly depending on the node configuration and the test environment. Some test cases were combined if the resulting range was very similar. To obtain satisfactory range in most conditions will require a dipole antenna and mounting of the nodes a half meter or more above ground level.

Table 1. Radio range under various conditions.

View	Antenna	Elevation (m)	Enclosed	Mean range (m)
VLOS	whip	0.5	No	51
Orchard	whip	0.5	No	23
VLOS	whip	0.5	Yes	33
Orchard	whip	0.6	Yes	16
VLOS/Orchard	whip	0	Yes/No	7
VLOS	dipole	0.8	N/A	98
Orchard	dipole	0.8	N/A	72
VLOS	dipole	1.7	N/A	217
VLOS/Orchard	dipole	0	N/A	32

Energy Management

The valve controller node has a radio current of 15 mA and a sleep current of about 80 μA (radio off). To extend battery life, nodes must be in sleep-mode most of the time and only use the radio when data transfer is required. This power-cycling feature is included with the wireless module software. The nodes spend most time in sleep-mode and synchronously wake every 128 ms to listen for radio activity from neighbors. If no activity is detected, the node returns to sleep. If the node were to send or receive radio messages every three minutes, the total battery consumption would be approximately 6.6 mA-h per day.

This energy use must be balanced by solar panel energy production in order to ensure perpetual operation of the valve controller. Solar panel performance was tested in full sunlight and full shade conditions. A datalogger recorded open-circuit voltage in full sunlight and output current from the panel through a 10 Ω load resistor for 19 days. Peak voltage was 12.7 V and peak current was about 15 mA in full sun and 1.5 mA in shade. Integration of current over time yielded a daily production of 52 to 81 mA-h in full sun and 6 to 10 mA-h in shade. Based on these tests, the solar panel should produce adequate energy for continuous operation.

Solar charging of the Ni-Cd battery was checked using two valve controllers, one with a solar panel and one without. They were placed outside for nine sunny days and set to transmit data messages every 15 seconds (higher rate than normal). These messages were logged every two minutes (Figure 6). The data collected included battery voltage and temperature inside the enclosure. It is evident by the voltage peaks that the solar panel charged the battery each day. However, the daily voltage low-point started to decrease after day 5 due to excessive heating of the enclosure. A daytime temperature over 40 °C resulted in a reduced battery voltage the following morning. This is possibly due to poor battery charging at high temperatures. Sunlight shielding of the enclosures will be necessary to protect the circuit and battery. Small voltage fluctuations were also seen for the non-solar node. These were due to changes in battery voltage and resistance during daily temperature variation.

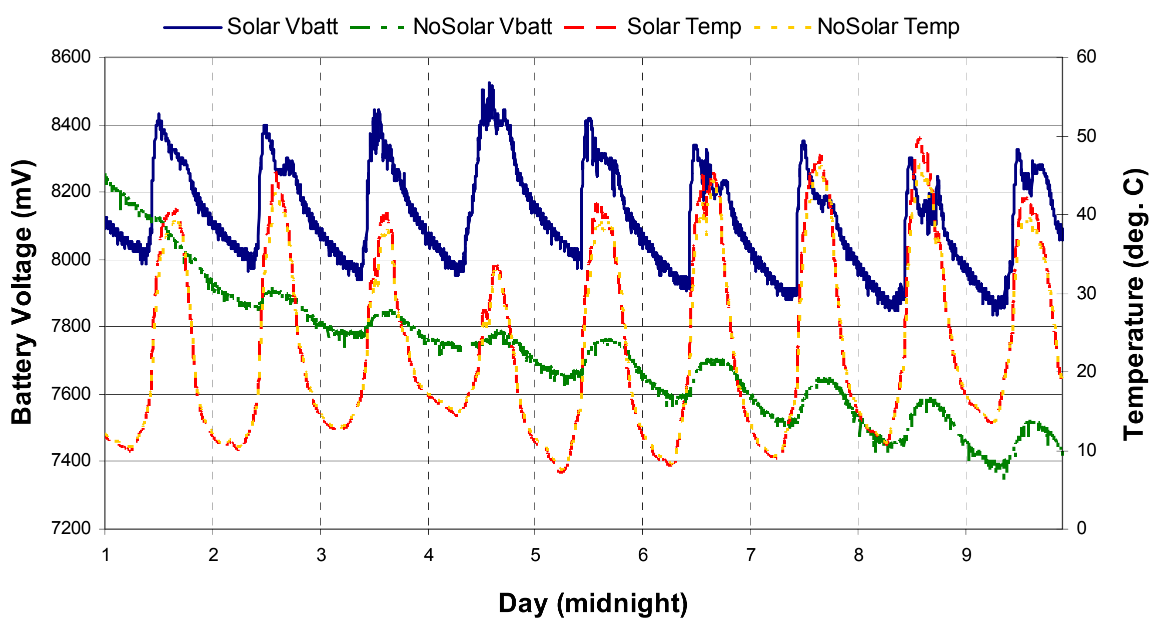

Figure 6. Battery voltage and temperature inside valve controller enclosures over 9 days.

Summary & Continuing Work

A wireless, solar-powered valve controller was built and tested. Mesh network communication was successful in allowing transmission and acknowledgement of valve actuation commands. The network range was dependent on antenna type, elevation above ground, and presence of obstructions. Energy management evaluation showed that a 200 mW solar panel should be adequate to continuously power the node if sunlight is available part time.

Continuing developments will include improved energy management techniques such as energy-use monitoring and solar panel switching to prevent battery overcharge. Sunlight shielding will be added to reduce enclosure overheating. Sensors will be connected to the nodes for monitoring water pressure, soil moisture level, and temperature. Sensors may also be used as feedback to indicate that valves are opening and closing properly. At the start of year 2 we will finish development of the network communication between the valve controllers and the field controller. This will allow the field controller to send irrigation schedules to the valve controllers and receive sensor data for storage. Several more nodes will be built and deployed in a landscape. We will then develop strategies for controlled irrigation and automated fault detection.