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Software design for wireless sensor-based site-specific irrigation

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ABSTRACT

In-field sensor-based site-specific irrigation management is of benefit to producers for efficient water management. Integration of the decision making process with the controls is a viable option for determining when and where to irrigate, and how much water to apply. This research presents the design of decision support software and its integration with an in-field wireless sensor network (WSN) to implement site-specific sprinkler irrigation control via Bluetooth wireless communication. Wireless in-field sensing and control (WISC) software was designed by four major design factors that provide real-time monitoring and control of both inputs (field data) and outputs (sprinkler controls) by simple click-and-play menu using graphical user interface (GUI), and optimized to adapt changes of crop design, irrigation pattern, and field location. The WISC software provides remote access to in-field micrometeorological information from the distributed WSN and variable-rate irrigation control. An algorithm for nozzle sequencing was developed to stagger nozzle-on operations so as evenly distributed over the 60-s cycle. Sensor-based closed-loop irrigation was highly correlated to catch can water with $r^2 = 0.98$.

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1. Introduction

Efficient water management plays an important role in irrigated agricultural cropping systems. Many areas of agricultural fields are effectively over- or under-irrigated due to spatial variability in water infiltration and runoff of rainfall and irrigation, crop water use and irrigation depth. Under-irrigated areas are subject to water stress, resulting in production loss, while over-irrigated areas suffer from plant disease and nutrient leaching. A wireless sensor-based irrigation control system is a potential solution to optimize water management by remotely accessing in-field soil water conditions and site-specifically controlling irrigation sprinklers. The system requires seamless integration of the system input and output components, and software design for decision support and monitoring.

Sensor-based irrigation systems have been studied for many applications (Stone et al., 1985; Jacobson et al., 1989; Zazueta and Smajstrla, 1992; Meron et al., 1995; Testezlaf et al., 1997). Stone et al. (1985) presented a computer-based monitoring system for continuous measurements of soil water potential. Zazueta and Smajstrla (1992) compared indirect estimates with direct measurement of soil moisture. Meron et al. (1995) used a control system for apple tree irrigation management using tensiometers. Testezlaf et al. (1997) used an automated irrigation control system for management of greenhouse container plants.

A well-designed irrigation system is an essential requirement for a profitable and environmental friendly irrigation (Abreu and Pereira, 2002). Wireless radio frequency technology has provided opportunities to deploy wireless data communication in agricultural systems (Oksanen et al., 2004; Zhang, 2004; Lee et al., 2002). Software design for automated irrigation control has been studied by Abreu and Pereira (2002). They designed and simulated solid-set sprinkler irrigation systems by using ISADIM software that allowed to the design of a simplified layout of the irrigation system. However, their software provided limited control due to the lack of feedback in-field sensors.

An automated irrigation system was proposed for remote in-field sensing and variable-rate irrigation control (Kim et al., 2008). The objective of this paper is to describe a user-friendly software design for decision support and monitoring of wireless sensor-based site-specific irrigation system.

A schematic flowchart of an automated irrigation system for variable-rate irrigation is illustrated in Fig. 1. The system consists of machine conversion, localization, and mission planning. The first requirement is to convert a self-propelled irrigation machine from a conventional mechanical and hydraulic system to an electronically controllable system for individual sprinkler head control. Then, it is necessary to be able to continuously monitor the geographic location of the irrigation machine by a self-positioning system. Once the machine is controllable and accessible to its navigation, mission planning must decide when to irrigate and how much water each sprinkler head should apply at each location. This decision support process updates watering instructions according to the cart location and field soil water conditions monitored from sensors distributed

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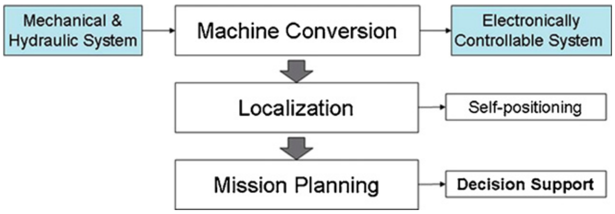

Fig. 1. Schematic flowchart of an automated site-specific sprinkler irrigation system for variable-rate irrigation.

across the field, and sends control signals to a nozzle controller at the irrigation machine.

2. Wireless sensor network (WSN)

A distributed WSN was developed for real-time in-field soil water content sensing (Kim et al., 2008). The network consisted of five sensing stations and a weather station. Each of the sensing stations contained a data logger (CR10, Campbell Scientific Inc., Logan, UT), two soil water reflectometers (CS616, Campbell Scientific Inc., Logan, UT) horizontally at the 30-cm and 61-cm soil depths each, and a soil temperature sensor (107, Campbell Scientific Inc., Logan, UT) at the 15-cm soil depth. The weather station measured precipitation, air temperature, relative humidity, wind speed, wind direction, and solar radiation. Sensors at the in-field sensing and weather stations were scanned every 10 s, and data were stored and wirelessly transmitted every 15 min via a Bluetooth radio transmitter (SD202, Initium Co., Korea) back to a base computer at a receiver (MSP-102a, Initium Co., Korea). All components at each station are self-powered by a 12-V battery that is recharged by a solar panel (SX5, Solarex, Sacramento, CA). The design for power management and wireless communication for the WSN was detailed by Kim et al. (2008).

The wireless sensor network was configured via transmission control protocol (TCP)/internet protocol (IP) to create a virtual serial network. The Bluetooth master at a base station operates as a TCP server, while other seven Bluetooth slaves are registered into TCP data ports. The server receives data from all seven in-field sensor clients and sends the data to the base computer via Ethernet. A serial emulator provides virtual COM ports and redirects to TCP socket connection (Fig. 2).

2.1. Machine conversion

A conventional irrigation machine needs conversion to adapt the in-field sensor-based variable-rate irrigation control. The machine used in the study was a ditch-feed, self-propelled linear-move irrigation system (Valmont Industries, Inc., Valley, NE) equipped with two different sprinkler application methods: mid-elevation spray application (MESA) and low energy precision application (LEPA) (Evans and Iversen, 2005). The irrigation system had six towers including the generator/pump/control cart located at the north end of the system. The machine moved at about 2 m/min at the 100% speed setting.

The machine was converted to make sprinkler nozzles electronically and individually controllable by attaching a programmable logic controller (PLC), solenoids, air valves, GPS, and radio transmitter. The PLC (S7-226, Siemens, Johnson City, TN) was mounted on a main cart and activated electric solenoids (U8325B1V, ASCO, Florham Park, NJ) to control 30 banks (15 for MESA banks and 15 for LEPA banks) of sprinklers via diaphragm valves (205, Bermad Inc., Anaheim, CA). The signal interface and software design for the PLC were detailed by Kim et al. (2008). The PLC updates the GPS position of the irrigation machine every second from a WAAS-enabled differential GPS (17HVS, Garmin, Olathe, KS) and wirelessly transmits the machine position to the base station via a Bluetooth radio transmitter. With feedback of in-field soil water conditions and the irrigation machine positions, the base station makes a real-time decision for site-specific irrigation and wirelessly sends individual sprinkler control signals to the PLC with a complete cycle of closed-loop control within a second via Bluetooth receiver.

2.2. Cost of WSN

The selection of the Bluetooth wireless system was based on communication range, data rate, and cost and intended to accommodate existing devices with plug-and-play type of wireless modules. The total cost of Bluetooth wireless modules used

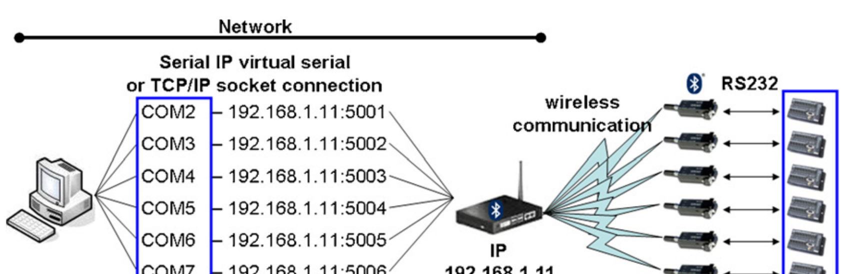

Fig. 2. Virtual serial network. The receiver is configured as a multi-serial Bluetooth server and each Bluetooth device has virtual COM ports and redirected to TCP socket connection.

Table 1
System cost for in-field wireless sensor network with a sensing station.

	Equipment	Unit price	Qt.	Total price
Wireless modules	Bluetooth transmitter (SD202)	$108	7	$756
	Bluetooth receiver (MSP-101a)	$425	1	$425
Sensing station	Soil moisture sensor (CS625)	$150	2	$300
	Soil temperature sensor (109-L)	$70	1	$70
	Data logger (CR200)	$390	1	$390
	Battery (YUASA NP7-12)	$13	1	$13
	Solar panel (SX5)	$90	1	$90
	Sum	$1246		$2044