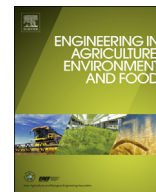




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Research paper

Design and testing of an autonomous irrigation controller for precision water management of greenhouse crops[☆]Hak-Jin Kim ^{a,*}, Dong Hoon Lee ^b, Sung Wook Ahn ^a, Won Kyung Kim ^a, Seung Oh Hur ^c, Jin Yong Choi ^d, Sun-Ok Chung ^e^a Department of Biosystems and Biomaterials Science & Engineering, Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, 151-921, South Korea^b Department of Biosystems Engineering, Chungbuk National University, Cheongju, 362-763, South Korea^c Department of Agricultural Environment, National Academy of Agricultural Science, Wanju-gun, Jeonju 565-851, South Korea^d Department of Landscape and Regional Systems Engineering, Seoul National University, Seoul, 151-921, South Korea^e Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon, 305-764, South Korea

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ABSTRACT

The automation of irrigation systems based on sensor technology has the potential to maximize the efficiency of water use. A prototype of an autonomous irrigation controller consisting of an 8-bit MCU and a 12-bit AD converter was developed and tested in tomato greenhouses. Two algorithms for water control, i.e. a variable keep–pause method and a required water calculation method, were programmed. The irrigation controller showed the ability to measure soil tensions in real-time and to properly trigger irrigation at a set value. The system performance for maintaining soil tensions based on the keep–pause method was strongly affected by sunlight, whereas the water calculation method provided a simple irrigation operation without frequent irrigation, while supplying the amount of water needed during each irrigation period.

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1. Introduction

Water is one of the most important resources for crop growth. Due to a rapid change in the global climate in recent years, there has been an increasing need to maximize the efficiency of water use at agricultural production sites. Under-irrigated areas are subject to water stress, resulting in production loss, while over-irrigated areas suffer from plant disease and nutrient leaching (Pereira et al., 2002). Maintenance of adequate soil water levels during the period of crop growth is necessary in order to support optimum plant growth and yields (Hansen and Pasian, 1999; Kim et al., 2009). An automatic irrigation control system plays an important role in efficiently saving water in irrigated agricultural cropping systems because it can supply the amount of water needed at the right time

according to plant needs and actual water conditions throughout the seasons (Boutraa et al., 2011; Muñoz-Carpena et al., 2008). In addition, recent technological advances in soil water sensing have made the commercial use of this technology possible in order to automate irrigation management for crop production (Boutraa et al., 2011; Dukes and Scholberg, 2005).

Such a soil water management system usually requires the use of an autonomous irrigation controller with a soil moisture sensor that can maintain soil water content within a specific range. This goal is achieved by variably regulating the on-off operation period of a solenoid valve based on the feedback of the soil water status (Kim et al., 2013). In addition, the amount of water to be supplied during each irrigation period is controlled based on the variation in water availability due to different soil characteristics or crop water needs (Miranda et al., 2005).

There are two types of soil moisture sensors commonly used for irrigation automation, those that measure soil water potential, i.e. tension or suction, and those that measure the volumetric water content directly (Dukes et al., 2010). Tensiometers have been used for many years as devices to give growers feedback on when to

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* Corresponding author.

E-mail address: kimhj69@snu.ac.kr (H.-J. Kim).

irrigate (Dukes et al., 2010). Recently, within the category of volumetric sensors, capacitance-based sensors based on the time domain reflectometry (TDR) and frequency domain reflectometry (FDR) have become more common as a result of a decrease in the cost of the electronic components and the increased reliability of these types of sensors.

Several researchers have studied the development of automatic irrigation controllers consisting of micro-processors used in conjunction with soil moisture sensors for precision irrigation. Miranda et al. (2005) developed an autonomous controller for the site-specific management of fixed irrigation systems. Soil matrix potential values obtained with granular matrix sensors (GMS) were used in order to control the amount of water applied to each specific management area of a field. The results showed that the solar power-operated controller was effective in maintaining the desired soil water range in the root zone of the crop. However, they did not report on the development of a new irrigation control logic to improve irrigation efficiency as compared to that used in a conventional switching tensiometer.

Similarly, Muñoz-Carpena et al. (2008) developed a low-cost controller using readily available components and coupled it with an inexpensive dielectric soil water probe. The electronic controller was designed to be easily adapted to existing commercial irrigation systems that currently use time clocks with a pressurized water supply. In their study, the combined variability of the soil and the water probes resulted in a relatively high level of variability in the water application, although the resulting variability in the yield response was less. However, even though they conducted a preliminary field evaluation of the developed controller against other conventional irrigation scheduling methods, data obtained from the field tests were used to primarily investigate the feasibility of using the developed irrigation controller with an inexpensive soil water probe for automatic irrigation.

The application efficiencies of micro-irrigation systems are typically high because these systems distribute water near or directly into the crop root zone. These highly efficient water systems are widely used on high-value vegetables in fields or greenhouses and on tree fruit crops in orchards because of their advantages over sprinklers, such as reduced water use, the ability to apply fertilizer with the irrigation water, more precise water distribution, and the ease of use with an automatic irrigation controller. When using the irrigation controller, the target soil water status is usually set in terms of soil tension or volumetric moisture (Boutraa et al., 2011). Switching tensiometers have been commonly used in soils to automatically control irrigation events based on preset soil matrix potential limits (Muñoz-Carpena et al., 2005). It was found that this type of switching tensiometer-controlled drip irrigation system set at 15 kPa on a tomato crop reduced irrigation by 70% in comparison to typical farming practices in South Florida sandy soil, while maintaining similar yields.

Soil moisture sensors are used to estimate the amount of water that needs to be supplied with each event based on the crop needs. However, since soil water characteristic curves relating water content to soil tension vary depending on the soil type, the soil information should be determined before an irrigation decision is made based on the moisture contents measured with these sensors. When using a tensiometer to measure the soil water status, an approach that builds a calibrated relationship between the soil tension and moisture content by soil type into the program of an irrigation controller would be useful, so that tension values can easily be converted into soil moisture values in order to determine the amount of water supplied for each irrigation event. In a previous study (Hur, 2007), we established equations that relate tensions to water contents applicable to Korean soils. However, there has been no trial to implement the required water calculation

method as an irrigation control logic applied to an irrigation controller.

When considering the use of an automatic drip irrigation system, the selection of an irrigation algorithm for optimal crop growth is important to maximize water use while maintaining crop yields. In this regard, we tried to develop an autonomous irrigation controller for Korean greenhouse cultivation in which various control logics for irrigation could be programmed. Specific objectives were to 1) develop an autonomous irrigation controller consisting of an 8-bit micro-control unit (MCU) and a 12-bit analog-digital (AD) converter that could control irrigation events based on either a variable keep–pause time method or a required water estimation method, and 2) perform a field evaluation conducted in tomato-growing greenhouses in order to investigate the effectiveness of using the autonomous irrigation controller for greenhouse cultivation in Korea.

2. Materials and methods

2.1. Prototype irrigation controller

2.1.1. System hardware and software

A prototype irrigation controller operated on AC 220 power was designed to autonomously control irrigation events based on the preset soil water status. The controller primarily consisted of a main board and three interface modules, i.e. input, output, and communication modules. The main board included an 8-bit ATmega2560 MCU, a real-time clock, a 12-bit analog-to-digital (AD) converter, wireless networks, and SD memory-based data storage. The input module could interface with the soil tensiometers transmitting analog signals using the AD converter with a 1.22 mV resolution over a full-scale voltage of 0–5 V DC. As shown in Fig. 1, the output module consisted of three different types of relays, i.e. 8 time-to-live (TTL)s with pull-up resistors, 8 magnetic relays, and 8 solid-state-relay (SSR)s. Various communication protocols, including RS232, Zigbee, and power line communication (PLC) were implemented for the network in the prototype. The main specifications of the controller are noted in Table 1.

In principle, the controller simultaneously collected electric outputs from 24 individual sensors connected to the input module and allowed a time clock 24-VAC signal to independently power 24 irrigation solenoid valves via the on-board latching relays. When the sensors indicated that the measured values exceeded the preset value, the irrigation controller opened the solenoid valves by switching the corresponding relays, thereby triggering irrigation by

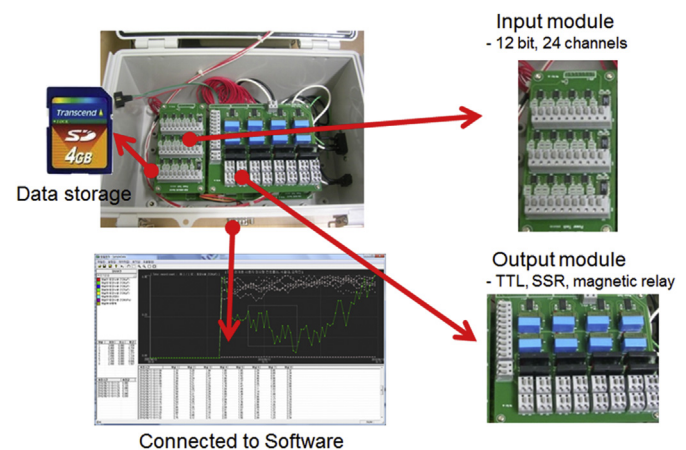


Fig. 1. The system hardware components of the prototype irrigation controller developed in the study.

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