REMOTE CONTROL SYSTEM FOR GREENHOUSE ENVIRONMENT USING MOBILE DEVICES

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ABSTRACT

Protected crop production facilities such as greenhouse and plant factory have drawn interest and the area is increasing in Korea as well as in other countries in the world. Remote control systems using either mobile devices (e.g., cell phone) or internet-accessible computers have been developed. Application of smart-phone has been tried to support communication with both text message and internet access recently, but performance tests at various conditions have been limited. Objectives of the paper were to construct a greenhouse simulator that the environments could be controlled electronically and automatically, and to evaluate remote control of the environments using mobile devices in various conditions. A small-sized greenhouse with dimensions of 2.6×3.8×2.2 m (W×L×H) was constructed as a simulator. Control factors were window motor, ventilation fan, light, heater/cooler and solenoid valve for irrigation, and sensing variables were air temperature and humidity, luminous intensity, and soil water content. Performance of the wireless control network was evaluated as control response time by number of control node, power consumption of the wireless control network.

Keywords : Greenhouse, Wireless control, Remote control

INTRODUCTION

For production of competitive crop and greater income, farmers need efficient cultivation and management techniques. Remote control of the environment for protected production facilities using wireless sensing and control technologies may increase crop yield and quality, and also reduce labor requirement (Wang et al., 2006; Garcia et al., 2009; Hwang et al., 2010). Gieling et al. (1996) proposed a greenhouse control system consisted of 4 sub-levels: 1st level to manage and operate sensors and equipment, 2nd level to integrate the 1st level units, 3rd level for communication, and 4th level to operate the entire system by users. Ameur et al. (2001) developed a modular measuring equipment using Micro Controller Unit (MCU) for cultivated land. It used eight-channel multiplexing card to measured temperature and humidity, and solar radiation and rainfall sensors were connected directly to the MCU, and then transferred to a server computer through RS-232 communication port.

Dukes et al. (2005) compared amount of used water in sensor-based and timer-based irrigation systems, and reported that 11% of the water could be saved in the sensor-based system. Park et al. (2011) constructed a sensor network using MCU, Zigbee protocol to measure temperature and humidity for greenhouse, and applied the sensor network for heater operation. Temperature and humidity were maintained in ranges of 20~25°C (mean: 23.7°C) and 70~80% (mean: 72.5%), respectively, which were considered as stable environments.

Lee et al. (2011) constructed a real-time remote monitoring system to obtain soil moisture, air temperature and humidity, solar radiation, and images, and send the data to an internet website. Hwang and Yoe (2011) proposed a context-aware middleware to manage greenhouse environment effectively. The proposed context-aware middleware could check sensor state, transfer the sensor data after digital signal processing, display the data on a screen and, control actuators. Communication times of the wireless sensor network (WSN) with and without the context-aware middleware were 0.47 and 0.58 seconds, respectively.

For remote sensing and control at locations without internet accessibility, cell phone based systems have been developed. Li et al. (2010) constructed a WSN for greenhouses to collect data at a 0.1-ms interval and transfer the data wo a web-page at an 1-minute interval via general packet radio service (GPRS) communication. An alarm short message service (SMS) was sent to users when the sensing values were deviated from certain setting values. Bae et al. (2011) developed a remote monitoring system for greenhouse environment using SMS of mobile phone. The monitoring message was composed of encrypted command because the SMS function had a limited capacity of 80 byte per message.

For successful implementation of wireless sensor or control network, stable operation and power consumption would be important issues to address. Niels and Jesper (2001) reported a web-based remote monitoring system that updated greenhouse information every 10 minutes. When the system was applied to monitor and control 20 greenhouses with 7 management computers for 2-year test period, 10 days of error was experienced due to network communication problems. Zhou et al. (2007) measured power consumption by state of sensor node. The sensor node consumed 0.35 and 0.55 mA for temperature and humidity sensing, respectively, and 9 and 44 mA for receiving and transmitting of the measured data.

Overall objective of the study was to develop a remote control system for greenhouse environment using mobile devices. Specific objectives were 1) to construct WCN for greenhouse environments and evaluate the performance, and 2) to evaluate performance of remote control using a mobile device.

MATERIALS AND METHODS

Construction of remote control system using WCN

Remote control system for greenhouse environment was consisted of three parts in the study: WCN part installed at multiple locations in a greenhouse, user part to monitor the environment and send control commands, and central management part to receive and process commands, and connect WCN and user (Figure 1). Each WCN node included MCU-based relay node and Zigbee communication module. User part utilizes mobile devices to send control commands using CDMA, 3G, or Wi-Fi communication. Central management program was coded in Visual Basic ver. 6.0 to process control commands and activate the WCN relay nodes.

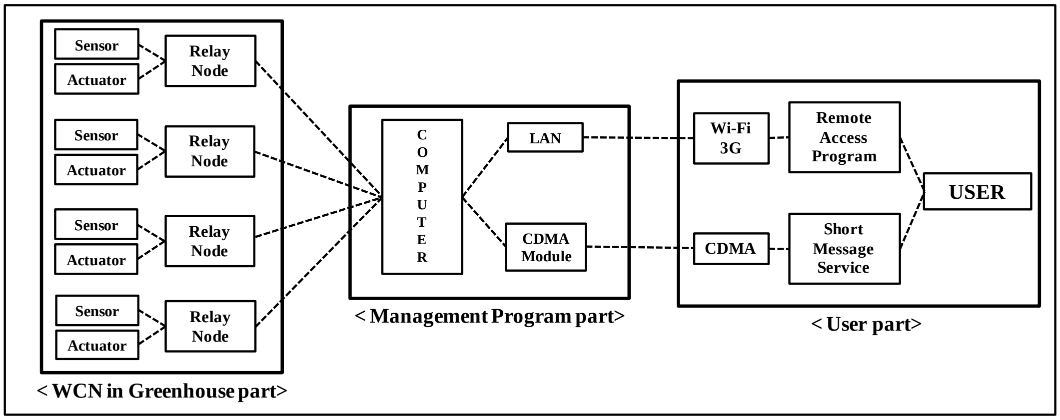

Figure 1. Schematic diagram showing concept of the remote control system using WCN and mobile device.

For long-term and various experiments, a small-sized greenhouse with dimensions of 2.6×3.8×2.2 m (W×L×H) was constructed as a simulator. The greenhouse-simulator composed 4 zones of independent WCN. Irrigation solenoid valve, heater/cooler, fan, light and window motor were installed in each WCN zone. An MCU (Model: ATmega128; ATmel Co. Inc., San Jose, CA, USA) was selected in the study. ATmega128 had a flash memory that could erase and rewrite 10,000 times, 8-bit and 16-bit timers and counters, 10-bit analog-to-digital (A/D) converters, two-wire serial interface, UARTs, serial peripheral interface, watch dog timer, analogue comparator and input/output.

For wireless communication, a Zigbee-based module (Model: XBee_Pro_Series1; Maxstream Co. Inc., Minnetonka, MN, USA) was used. The communication module featured low power consumption, micro-sized and low cost module. It could transfer data in a 250-kbps speed among up to 65,000 nodels within 10~20 with the IEEE802.15.4 communication protocol.

Performance evaluation of the remote control system

Performance of the remote control system was evaluated in terms of communication success ratio, response time, power consumption. Time required to activate relay node was measured by number of node. Response time to control environment was also measured. Irrigated water was monitored for 15 minutes on 1-minute intervals. Response time of the window motor was evaluated for different partial opening and closing levels. For heating and ventilation, temperature and humidity sensors were installed at 1-m distance from the heater and fan. Illumination intensity was measured under the light source. For each WCN component, power consumption was also evaluated.

RESULTS AND DISCUSSION

Figure 2 shows examples of elapsed time from input of control command at the central management part to activation of relay node at the WCN part. The elapsed time was not changed by number of relay nodes up to 10. Mean elapsed times were 279, 302, 292, 299, 299, and 736 ms for solenoid valve, irrigation pump, ventilation fan, light, window motor, and heater/cooler, respectively, indicating all of the equipment could be activated within 1 s from the time of user command input.

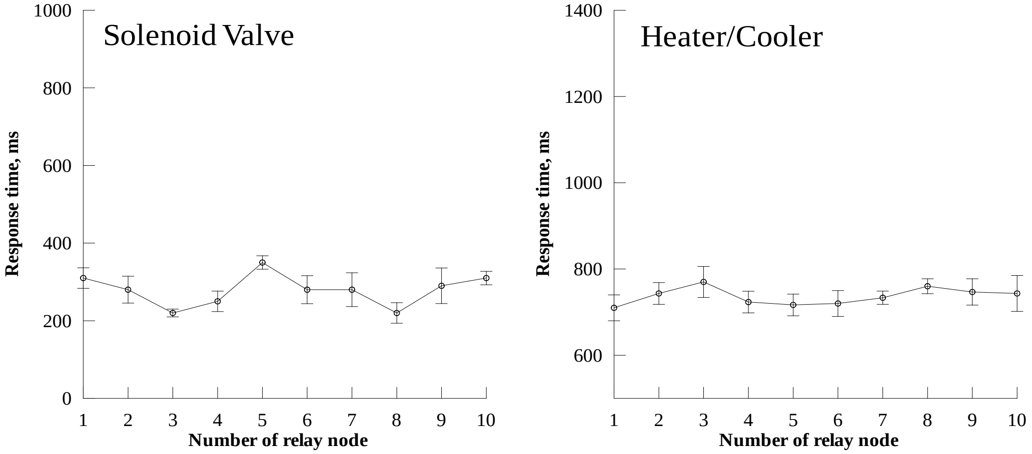

Figure 2. Examples of elapsed time for activation of relay by number of node.

Figure 3 shows irrigated water at each drip opening, level of window opening, and changes in temperature and humidity as elapsed time after activation of relay node. Both of the irrigation and window operation showed linear patterns, irrigated rate was 2.76 mL/min, and required time to control window opening by 10% of the full range was about 11.14 s. Inside and outside temperature values were both 16°C and humidity values were 60 and 66%, respectively. With heater operation, inside temperature increased logarithmically and was maintained at 24±0.5°C after 2 hours. Air relative humidity was decreased to 50% after 20 minutes, and maintained at 43±0.5% after 2 hours.

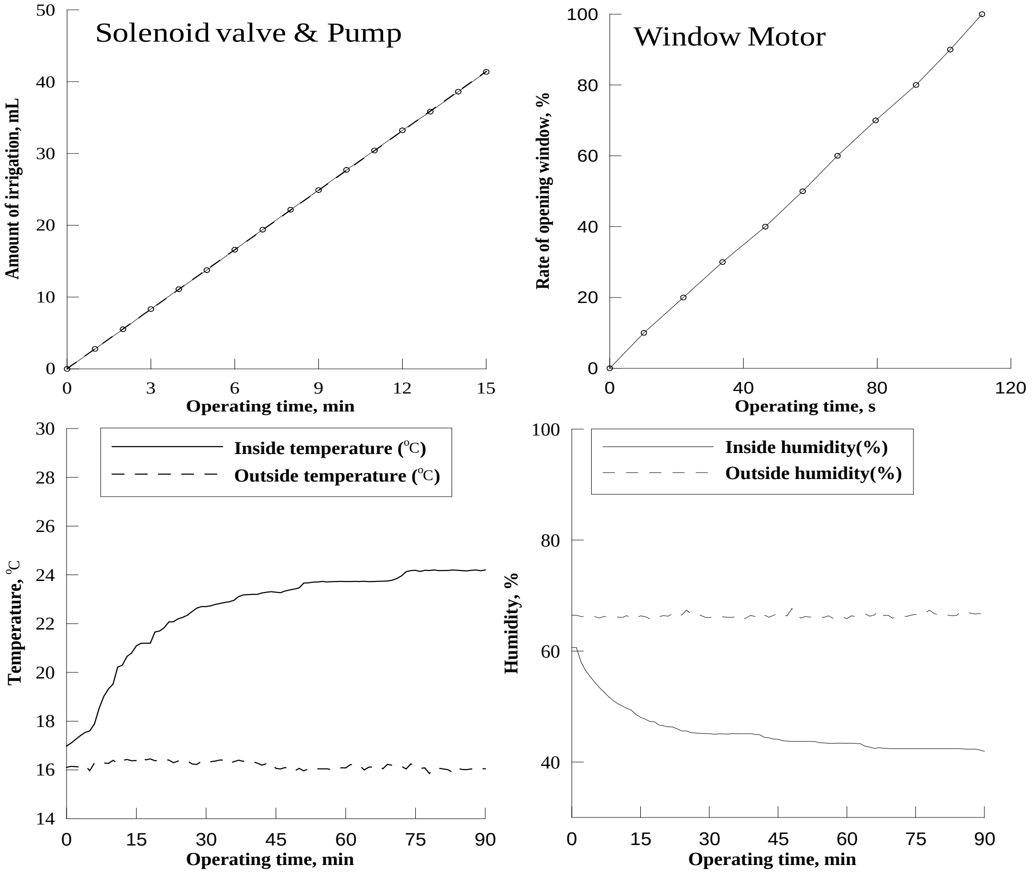

Figure 3. Irrigated water (left top), window opening (right top), temperature (left bottom), and humidity (right bottom) by operating time.

Result of Performance Evaluation of Remote Control System

Tables 1~3 summarizes number of success and response time for remote access under different wireless communication conditions. Communication and remote control was successful for all cases. Depending on location, response times were less than 14 seconds for Wi-Fi communication conditions. For 3G communication, response times were 10.55 and 15.71 seconds for stationary (0 km/h) and high speed (100 km/h) conditions, respectively. They were less than 12.35 seconds for sending remote control command using CDMA SMS service.

Table 1. Performance of remote access under Wi-Fi condition

	High Signal Intensity			Low Signal Intensity		
	Home	Office	Hotspot	Home	Office	Hotspot
No. of success	30	30	30	30	30	30
Response time (s)	4.82	7.26	12.86	14.22	14.29	14.82

Table 2. Performance of remote access under 3G condition

	0 km/h	100 km/h
No. of success	30	30
Response time (s)	10.55	15.71

Table 3. Performance of remote access under CDMA condition

	-95 ~ -80 (dBm)	-79 ~ -60 (dBm)
No. of success	30	30
Response time (s)	12.35	9.84

Figure 4 shows example plots of power consumption for activation and operation of the environmental control components. Generally, actual power consumption levels were lower than the rated levels. For solenoid value, power level was about 2.11 W, which was greater than the rated level, but decreased and stably maintained at about 1.61 W. Initial operation of the irrigation pump required about 193.25 W, and the level increased up to 236.97 W with full amount of water flow, but they were lower than the rated power consumption level. The heater-cooler consumed the greatest power with average of 1753.43 W and the maximum of 2957 W at the initial operation period. Ventilation fan and lighting bulb required about 26.23 W and 18.93 W, respectively. Window more required 54.86 W, while a relay node required about 0.41 W. Estimation of power consumption during crop production should consider duration and interval of operation.

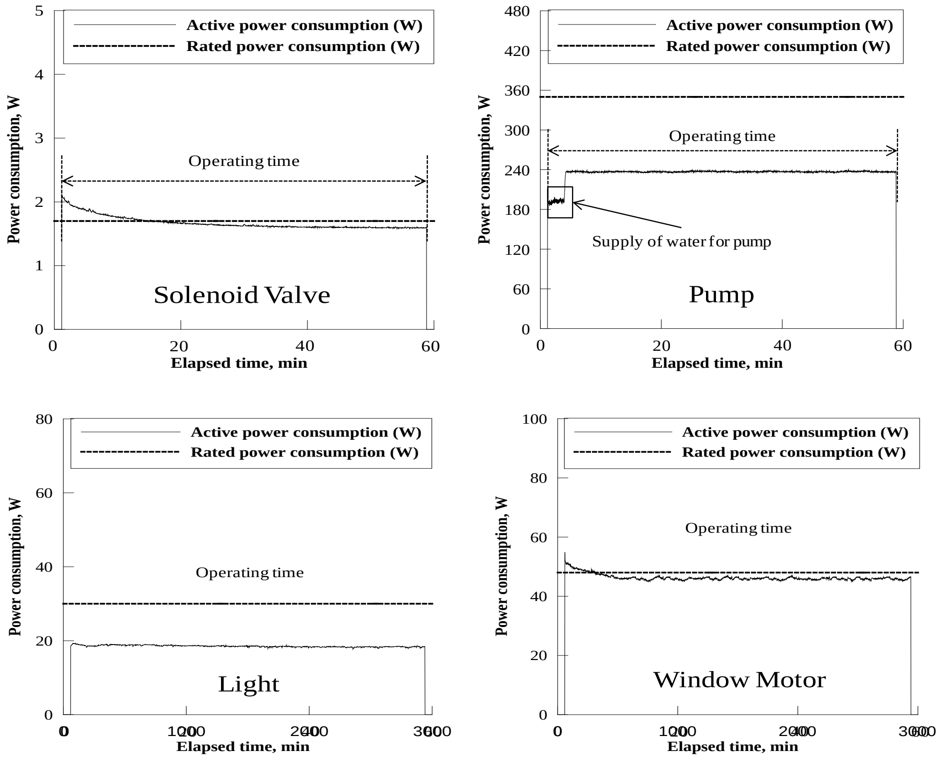

Figure 4. Power consumption of actuators by operating time.

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