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Implementation of Remote Monitoring Scenario using CDMA Short Message Service for Protected Crop Production Environment

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Abstract

Protected vegetable production area is greater than 26% of the total vegetable production area in Korea, and portion of protected production area is increasing for flowers and fruits. To secure stable productivity and profitability, continuous and intensive monitoring and control of protected crop production environment is critical, which is labor- and time-consuming. Failure to maintain proper environmental conditions (e.g., light, temperature, humidity) leads to significant damage to crop growth and quality, therefore farmers should visit or be present close to the production area. To overcome these problems, application of remote monitoring and control of crop production environment has been increasing. Wireless monitoring and control systems have used CDMA, internet, and smart phone communications. Levels of technology adoption are different for farmers' needs for their cropping systems. In this paper, potential of wireless remote monitoring of protected agricultural environment using CDMA SMS text messages was reported. Monitoring variables were outside weather (precipitation, wind direction and velocity, temperature, and humidity), inside ambient condition (temperature, humidity, CO_2 level, and light intensity), irrigation status (irrigation flow rate and pressure), and soil condition (volumetric water content and matric potential). Scenarios and data formats for environment monitoring were devised, tested, and compared. Results of this study would provide useful information for adoption of wireless remote monitoring techniques by farmers.

Keywords : Protected crop production, CDMA communication, SMS, Remote monitoring

1. INTRODUCTION

Protected crop production has been more popular in many countries to overcome unexpected damage on crop production due to climate change and for better crop yield and quality. In Korea, agricultural area was decreased from 1,889,000 ha in 2000 to 1,737,000 ha in 2009, but protected production area was increased from 94,508 ha in 2007 to 97,300 ha in 2009. Major crops produced in protected facilities are high-value crops such as leaf vegetables, fruit vegetables, and flowers (KAMICO and KSAM, 2010).

Environmental factors such as air conditions (e.g., ambient air temperature and humidity, CO_2 concentration, and light intensity) and soil conditions (e.g., water content, nutrient concentration, pH) affect crop growth, yield, and quality significantly. There are optimum ranges of these factors, favorable to crops. If environmental conditions are out of these ranges, crop growth, yield, and quality could be damaged considerably.

Paz et al. (1998) stated that soil water content caused the reduction of soybean yield by 69% from 3-year research

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relating root depth, hydraulic conductivity and water content of soil. Adams et al. (2001) investigated effects of different temperature levels (i.e., 14, 18, 22, and 26℃) on dry matter content during tomato maturation. After 27 weeks, dry matter contents at temperatures of 18℃ (72.0%) and 22℃ (75.1%) were greater than those at 14℃ (49.4%) and 26℃ (29.1%), indicating that temperature difference of 4℃ could cause differences in tomato yield. Experiments of tomato weight at different air temperature showed that mean tomato weights were 75.8, 73.8, and 62.2 g at temperatures of 15, 20, and 25℃, respectively. In experiments of hydroponic cultivation of cucumber in a greenhouse, Sanchez-Guerrero et al. (2009) reported that CO_2 supply and maintaining the concentration in a range of 400 ~ 500 μmol/mol increased nitrogen uptake by 18% and dry matter by 19% by cucumber, compared with the case of no CO_2 control. Recently in Korea, effects of spectral light intensity on plant growth (Lee et al., 2010) and autonomous guidance system for greenhouse operation (Hong et al., 2009) were reported.

Because environmental factors affect crop growth, yield, and quality considerably, it would be preferable to maintain those factors within optimum ranges using real time monitoring and control, especially in protected crop production. Manual monitoring and control of these environmental factors are time- and labor-consuming, and also tedious. Matese et al. (2009) implemented wireless monitoring system for precision grape production. The monitoring system was consisted of wireless sensor nodes spaced considering stable data transmission distance, and provided year-round weather information and battery consumption in one-day intervals to users. Li et al. (2010) constructed wireless sensor network for environmental monitoring of a vegetable production greenhouse with a low management cost. The network could collect and transmit air temperature and humidity, and soil water content for more than 6 months in 10-minute intervals a with 4.2 V-2AH (8.4 Wh) battery. Mahan et al (2010) implemented a wireless temperature monitoring system using low-cost infrared sensors. Variations of temperature with height could be monitored with temperature measurements at multiple crop heights. The system collected data on a 1-minute interval and transmitted to a PC on a 15-minute interval, and successful data transmission ratio was about 97.7%.

Remote control systems have been also researched. Coates and Delwiche (2009) controlled irrigation equipment from an office PC using a Zigbee-based wireless communication module. The system also remote-monitored and used field environmental data for timely irrigation scheduling for optimum crop growth. As discussed, remote monitoring and control of agricultural environment provide more scientific decision for optimum crop production and relieve farmers from fields. Remote monitoring and control system could be developed with different levels: access to internet websites using PC or PDA devices, smart phone and applications under 3G or Wi-Fi conditions, or SMS (Short Message Service) with mobile phones (Heo et al, 2002; Lim et al., 2003; Kong et al., 2003; Kim and Hwang, 2003; Shim et al., 2004).

Garcia-Sanchez et al. (2011) reported a remote monitoring system that camera, motion detecting sensor, and environmental data (soil water content, salinity, pH, and temperature) from multiple fields could be accessible from an internet website and cell phones. Data sizes for environmental factors, and image and motion detection were 35 bytes, and 105 bytes, respectively, and data update interval was 30-minute. Sensor data collected by Li et al. (2010) was 13 bytes. When the data was transmitted for 6 months on a 10-minute interval, transmission error was within ±2%. Lopez et al. (2011) implemented a remote monitoring system for precision horticulture. Wireless sensor network was constructed to collect air temperature and humidity, soil water content, electrical conductivity, and salinity from scattered multiple cabbage fields, and to transmit the data to an internet website so that users could monitor from PC and PDA devices. Design maximum single data size was 127 byte, and required sizes were 30, 6, 4, and 4 bytes for soil, air, battery status, and other auxiliary data, respectively. Cost could be reduced by selection of proper minimization of transmission interval.

Data size and cost of a remote monitoring and control system is affected by number and form of variables, and also monitoring and control interval. For example, continuous transmission of precipitation data is not necessary when there is no rain. Previous research has been focused on mainly implementation and evaluation of remote monitoring and control systems, but not on optimum data transmission options suitable for different user needs.

This study was conducted to evaluate different CDMA wireless communication scenarios and different levels of data forms using SMS for remote monitoring of protected agricultural environment.

2. MATERIALS AND METHODS

A. CDMA SMS for Remote Monitoring of Protected Crop Production Environment

SMS is one of the simplest data transmission methods that can be used for monitoring and controlling the environment of protected crop production facilities. This SMS service can be used whenever cell phones can access to local 2G communication antenna, while web-based or smart phone applications require internet accessibility (i.e., 3G capability). Data size of single SMS message is 80 byte, therefore efficient use of the data size would be necessary.

Figure 1 shows concept of remote monitoring and control of protected crop production environment using SMS of CDMA wireless communications. On-site PC collects environmental data and outputs control signal for greenhouses, and also is connected to a CDMA module that could transmit and receive data to and command from remote users through SMS messages. Major specifications of the CDMA module (Model: BSM-856; m2mnet, Korea) used are summarized in Table 1. A software receiving data from sensors, formatting for each scenario, transferring the monitoring data to user, and also receiving and responding to the commands from user was developed using Visual Basic version 6.0. Monitoring variables and their ranges were summarized in Table 2. Selected variables were for outside weather (air temperature, humidity, precipitation, and wind speed), inside air condition (air temperature, humidity, CO_2 concentration, and illumination intensity), inside soil condition (soil water content), and irrigation status (water flow rate and water pressure).

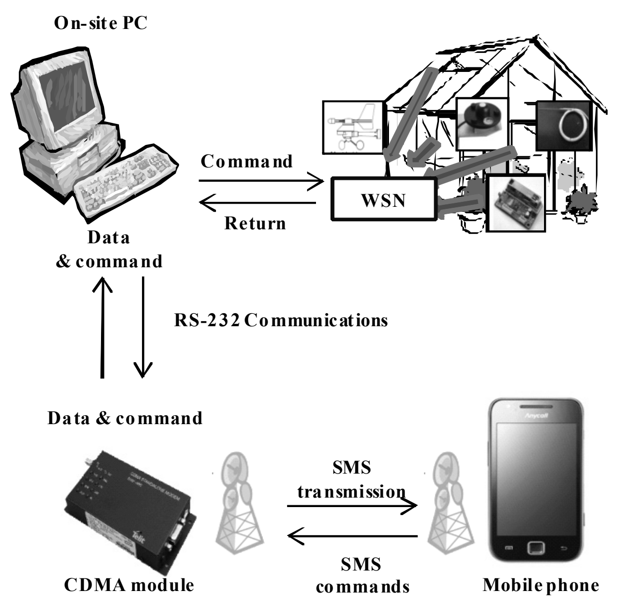

Fig. 1 Concept of remote monitoring and control of protected crop production environment using SMS of CDMA wireless communications.

Table 1 Specifications of the CDMA module used in the study

Item	Specification
Model	BSM-856
Receiving frequency range (MHz)	869-894
Transmitting frequency range (MHz)	824-849
Data transmission speed (kbps)	Up to 153.6
Dimensions (mm)	116×59×20 (L×W×H)
SMS cost (Korean Won)	20
Antenna connector	SMA type
Modem I/F connector	D-SUB9
Air - interface	IS-95A/B, CDMA 2000 1×RTT

Table 2 Environmental monitoring variables and their ranges used in the study

Variable	Range
Outside air temperature (℃)	-39.8 ~ 59.8
Outside air humidity (% RH)	1 ~ 99
Rainfall (mm)	0 ~ 393.7
Wind speed (m/s)	0 ~ 49.9
Inside temperature (℃)	-200 ~ 590
Inside humidity (% RH)	0 ~ 100
Intensity of illumination (μmol/m^2s)	0 ~ 2,500
CO^2 concentration(ppm)	0 ~ 3,000
Soil water content (% VWC)	0 ~ saturation
Water flow rate (mL/min)	20 ~ 100
Water pressure (psi)	0 ~ 1,000

B. Monitoring Scenarios

Interval, number of variables, and format and size of data were varied by monitoring scenario. For example, CDMA module may transmit all the 11 variable data regularly, or send part of the data when event occur (e.g., precipitation is not necessary when there is no rain). Message can be transmitted regularly, or only when requested by user. Message could be in either encrypted or not encrypted formats (Table 3).

Performance of the wireless monitoring scenario was evaluated. CDMA wireless communication would be affected

Table 3 Summary of monitoring scenarios

Item	Variety
Monitoring interval	Regular sending Sending when event occurs Sending by user request
Number of variables	All data Selected data
Message format	Encrypted form Not encrypted form

by RF signal intensity. The communication performance was tested with 20 SMS trials each of 4 RSSI (Received Signal Strength Indication) levels from -110 to -40 dBm. Success ratio and communication time were calculated.

3. RESULTS AND DISCUSSION

Table 4 summarizes defined data format and required size. Numbers in the “data format” column are maximum values of the measurements. For example, message in the format of “Air temperature: 99.9℃” required 22 bytes, and message containing all of the four weather variables required 75 bytes. Therefore, one SMS message was enough up to grouped data as weather, inside air, and irrigation status, but 3 SMS messages are necessary for all of the 11 variables. Data size was different for different measurement values (e.g., 5℃ vs. 30.9℃). Figure 2 explains that required data size varied from 171 to 195 bytes, depending on measurement values. When measurement values are minimum, size of the numerical data part is reduced from 40 to 16 bytes.

Although environmental monitoring data could be sent to users regularly, users may want to monitor their greenhouse environment only when they need data to reduce data service cost. Data size could be also reduced if data are encrypted (Table 5). For example, “TO” may be used for requesting outside air temperature and “WA” for all the weather data. Figure 3 shows example of user request using “WA” command and the received weather information.

Monitoring data can be also encrypted for reduction of SMS message size. For example, “Outside air temperature: 99.9±C” may be encrypted as “AT:99.9” as shown in Table 6. Using such an encryption, total data size could be reduced to 72 bytes including spacing between the variables, the size that could be sent with a single SMS.

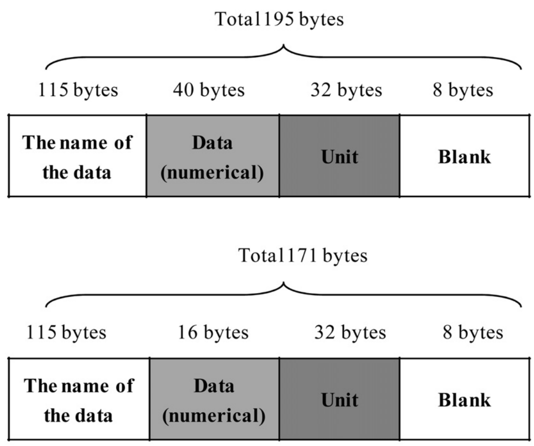

Fig. 2 Block diagram of electric actuator control system.

Table 4 Defined data format and required size for the selected environmental monitoring variables

Variable		Data format	Data size (Byte)	
			Single data	Group data
Weather	Outside air temperature	Air temperature: 99.9℃	22	75
	Outside air humidity	Air Humidity: 100%	17	
	Rainfall	Rainfall: 20.0 mm	15	
	Wind speed	Wind Speed: 20.0 m/s	18	
Inside air	Inside temperature	Temperature: 23.2℃	18	70
	Inside humidity	Humidity: 100%	13	
	Intensity of illumination	Illumination: 2500 μmol/m^{2}s	25	
	CO_2 concentration	CO_2: 3000 ppm	11	
Irrigation	Soil water content	Soil Moisture: 100%	18	50
	Water flow	Flow: 100 mL/min	14	
	Water pressure	Pressure: 1000 psi	16	
Total (including data spacing)				195

Table 5 Example of encryption of user commands

Variable	Encrypted command	
	Single	Multiple
Outside air temperature	TO	WA
Outside air humidity	HO	
Rainfall	RO	
Wind speed	SO	
Inside temperature	TI	IA
Inside humidity	HI	
Intensity of illumination	LL	
CO_2 concentration	CI	
Soil water content	SW	OA
Water flow	FW	
Water pressure	PW	

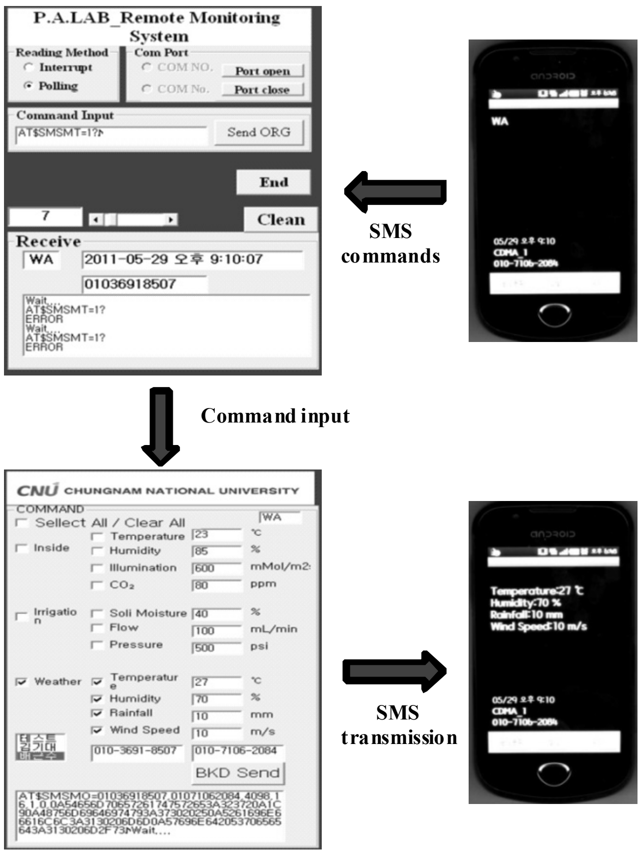

Fig. 3 Example of weather monitoring using "WA" user command.

Communication performance was very promising. Except RSSI levels less than -100 dBm, the level indicating that local antennas of communication service provider could not be accessed, all of the communications were successful at other RSSI levels greater than -100 dBm (Fig. 4). Averaged required times for regular receiving of monitoring data and monitoring by user request were 3 and 7.5 s, respectively.

Table 6 Encrypted format and required data size for the selected environmental monitoring variable

Variable		Data format	Data size (Byte)	
			Single data	Group data
Weather	Outside air temperature	AT:99.9	7	28
	Outside air humidity	AH:100	6	
	Rainfall	R:20.0	6	
	Wind speed	W:20.0	6	
Inside air	Inside temperature	T:23.2	6	26
	Inside humidity	H:100	5	
	Intensity of illumination	I:2500	6	
	CO_2 concentration	CO_2:3000	6	
Irrigation	Soil water content	S:100	5	18
	Water flow	F:100	5	
	Water pressure	P:1000	6	
Total (including data spacing)				72

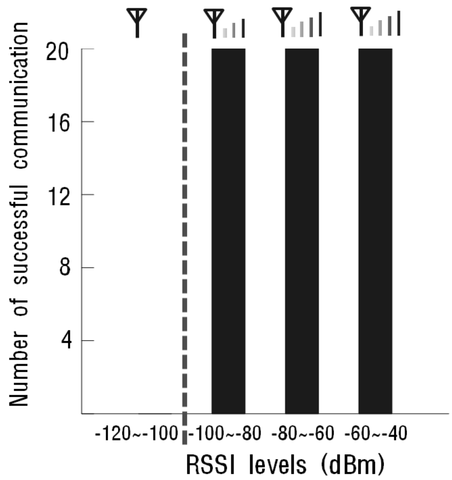

Fig. 4 SMS communication performance by signal intensity (20 trials per each level).

4. CONCLUSIONS

In the study, different CDMA wireless communication scenarios using SMS for remote monitoring of protected crop production environment were suggested, and performance of wireless monitoring was evaluated. Major findings were summarized as followings.

(1) Data format and size of the environmental variables were suggested. Considered variables were outside weather data (temperature, humidity, precipitation, and wind speed), inside air condition (temperature, humidity, light intensity, CO_2 concentration), and irrigation status (soil water content, water flow rate, and water flow pressure). User-friendly format required 195 bytes for monitoring of all the variables, but encrypted format required only 72 bytes, the size which monitoring data could be sent in a single SMS message.

2) User could request all or part of the monitoring data using encrypted user commands. Remote monitoring of environments for protected crop production was successful at the RSSI levels greater than -100 dBm. Averaged required times for regular receiving of monitoring data and monitoring by user request were 3 and 7.5, respectively.

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