Evaluation of wireless communication devices for remote monitoring of protected crop production environment

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시설재배지 환경 원격 모니터링을 위한 무선 통신 장비 평가

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Received on 28 September 2011, revised on 10 October 2011, accepted on 18 December 2011

Abstract : Wireless technology has enabled farmers monitor and control protected production environment more efficiently. Utilization of USN (Ubiquitous Sensor Network) devices also brought benefits due to reduced wiring and central data handling requirements. However, wireless communication loses signal under unfavorable conditions (e.g., blocked signal path, low signal intensity). In this paper, performance of commercial wireless communication devices were evaluated for application to protected crop production. Two different models of wireless communication devices were tested. Sensors used in the study were weather units installed outside and top of a greenhouse (wind velocity and direction, precipitation, temperature and humidity), inside ambient condition units (temperature, humidity, CO_2, and light intensity), and irrigation status units (irrigation flow and pressure, and soil water content). Performance of wireless communication was evaluated with and without crop. For a 2.4 GHz device, communication distance was decreased by about 10% when crops were present between the transmitting and receiving antennas installed on the ground, and the best performance was obtained when the antennas were installed 2 m above the crop canopy. When tested in a greenhouse, center of a greenhouse was chosen as the location of receiving antenna. The results would provide information useful for implementation of wireless environment monitoring system for protected crop production using USN devices.

Key words **:** Ubiquitous sensor network, Wireless communication, Remote monitoring, Protected crop production

I. Introduction

Protected crop production has advantages that crops can be grown year-round regardless of climate conditions and the growth, yield, and quality could be controlled, and the area of protected crop production is increasing in Korea as well as other countries in the world for better control of cultivation environments (i.e., air and soil conditions). Especially, protected cultivation of leaf and fruit vegetables and flowers are popular in Korea. Area of protected crop production increased from 94,508 ha in 2007 to 97,300 ha in 2009. As of 2009, area and production ratios of protected cultivation were about 22% and 12% for leaf vegetables, and 85% and 90% for fruit vegetables out of the total vegetable cultivation (KAMICO and KSAM, 2010).

Conditions of air (temperature, humidity, CO_2 concentration, and light intensity) and soil (water content and nutrient concentrations) affect significantly growth, yield, and quality of crops. Adams et al. (2001) investigated effect of different temperature

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levels (14, 18, 22, and 26°C) during tomato maturation. After 27 weeks, dry matter contents at temperatures of 18°C and 22°C were greater than those at 14°C and 26°C. Sizes at 18 and 22°C were 2~3 times greater than those at other temperatures. 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.

Farmers should be present at or visit frequently to crop production site to maintain environments within optimum ranges. Monitoring and control systems using information technology would be necessary for efficient management of crop production environments. Remote wireless monitoring and control would be a solution that farmers can be away from the production sites since the environments could be monitored and controlled from remote sites. Recently, monitoring systems using wireless sensor networks have been reported for efficient monitoring of environmental variations within the production sites (Heo et al, 2002; Lim et al., 2003; Kong et al., 2003; Kim and Hwang, 2003; Shim et al., 2004). Hwang et al. (2010) applied ubiquitous sensor network technology for paprika production. The sensor network was fabricated with 2.4 GHz RF chips and applied to measure air temperature and humidity, and leaf temperature and humidity.

Performance of wireless communication might be affected by communication distance and obstacles among the antennas. Coates and Delwiche (2009) tested effects of antenna height on transmission distance for two types of antennas (1/4-wave whip and 1/2-wave dipole antennas). When there was no crops, transmission distances were 20.9 and 205.2 m at 0 and 3 m whip antenna heights, and they were 32.7 and 241 m at 0 and 3 m dipole antenna heights, respectively. With crops, the distances decreased to 21.7 and 119.4 m for whip antenna and 30.0 and 145.9 m for dipole antenna at 0 and 3 m heights, respectively.

Li et al. (2010) tested a wireless sensor at different transmission distances from 20 m to 130 m on a 10-m interval with 0.05, 0.4, and 1 crop heights. Heights of transmitter and receiver from the ground were also varied as 1, 2, and 3 m. Transmission success ratios were 92.2 and 98.9% for 0.05-m crop height, and they were 2.1 and 62.9% for 1-m crop height, for antenna heights of 1 and 3 m, respectively. Vellidis et al. (2008) stated that communication success ratio was reduced when transmitting and receiving antennas were installed at heights less than crop height, due to plant biomass. Lee et al. (2008) tested wireless sensor network at open field and greenhouse. At open fields data could be transmitted stably up to 50 m, but inside greenhouse data loss ratios were 5 and 10% at 30 and 50 m distances, and the loss was attributed to metal materials. Therefore suitable antenna heights and locations should be investigated for stable and efficient utilization of wireless sensor network in greenhouse.

This study was conducted to evaluate performance of wireless communication devices for remote environmental monitoring of greenhouses. Specific objectives were 1) to test communication distance of wireless devices at open fields, and 2) to determine locations of antennas for stable environmental monitoring in a greenhouse.

II. Materials and methods

1. Construction of wireless sensor network

Selected variables for environmental monitoring of greenhouses were air temperature, humidity, precipitation, and wind speed for outside weather, air temperature, humidity, CO_2 concentration, and illumination intensity for inside air condition, and inside soil condition (water content). Table 1 summarizes selected variables and measurement ranges.

Two types of popular wireless communication devices were selected considering length of standard

Table 1. Selected sensors for greenhouse environmental monitoring 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 ~ 2500
CO_2 concentration (ppm)	0 ~ 3000
Soil water content (%, VWC)	0 ~ saturation

Table 2. Major specifications of the wireless communication systems used.

System type	Item	Specifications
A	Power (W)	2.0
	Range (m)	91
	Antenna	Omni Antenna
	Frequency (GHz)	2.4
B	Power (W)	0.1
	Range (m)	60 m
	Frequency (MHz)	915

Korean greenhouse (i.e., 100 m). One was a 2.4 GHz Zigbee wireless device with Modbus protocol (Model: ZP24D-250RM-SR; B&B Electronics Co. Inc., Dayton, OH, USA; referredas A type) for environmental variables inside greenhouse. The other was a 915 MHz device (Model: WS-2812U-IT; La Crosse Technology Ltd., La Crosse, WI, USA; referred as B type) for outside weather variables. Major specifications of the wireless communication systems were shown in Table 2. Data from the sensors were measured on a 1-s interval.

2. Experimental methods

Maximum transmission distance was tested with and without crop (barley in the study) for both wireless communication systems. Relative height and distance of transmission and receive antennas were varied from 0 to 3 m on a 1-m interval and from 0 to 120 m on a 10-m interval, respectively (Fig. 1).

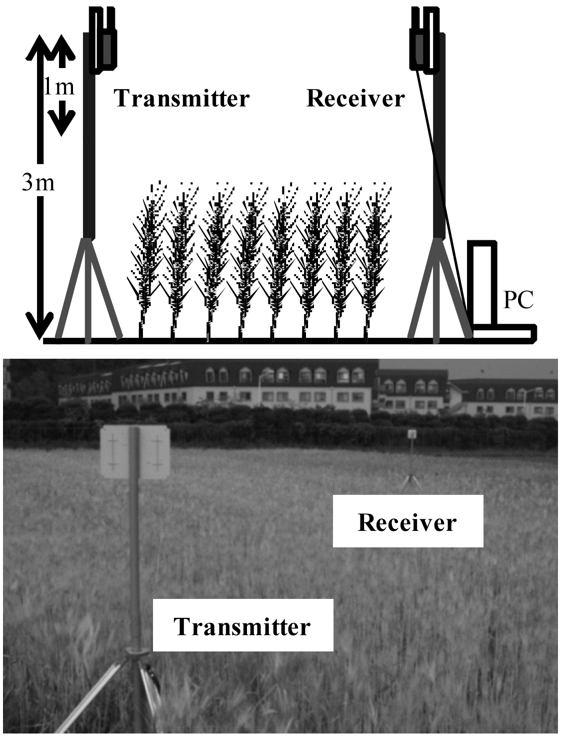

Fig. 1. Experimental set-up for evaluation of transmission distance at different antenna heights.

Similar experiments were also conducted inside a tomato production greenhouse (Fig. 2). Dimensions of the greenhouse (length, width, and height) were 85, 8, and 3.5 m, which were similar to the standard dimensions of Korean greenhouse. Transmission locations were center and right corner of the greenhouse and receiver locations were inside and outside of the left side boundary to simulate that data was collected at a corner of the greenhouse. Experiments simulating data collection at the center of the greenhouse was also conducted. In the wireless communication experiments, 100 trials on a 1- s interval were conducted with 3 replications.

III. Results and discussion

1. Performance of wireless data trans-mission distance at open fields

As expected, transmission success ratio decreased

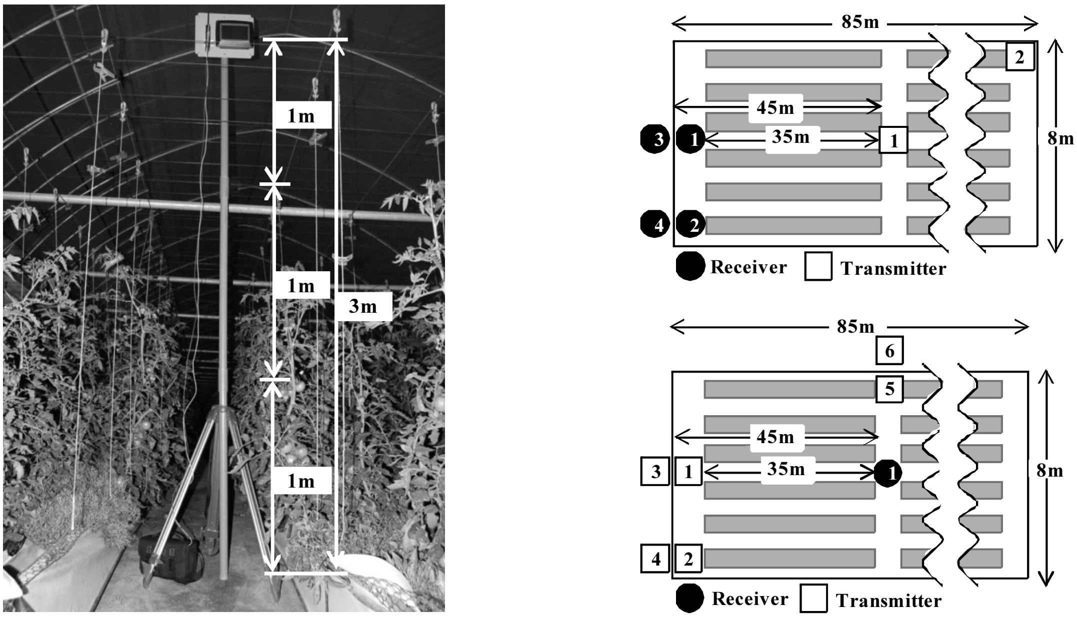

Fig. 2. Photo of experimental setup for wireless communication inside a greenhouse (left), schematic diagrams explaining experiments for data collection at a corner of the greenhouse (right top), and at center of the greenhouse (right bottom).

Table 3. Communication success ratio at open fields without crop (A type device, %).

Receiver height	Transmitter height	Distance of wireless communication							
		50m	60m	70m	80m	90m	100m	110m	120m
0 m	0 m	100	100	100	90	62	16	0	0
1 m	0 m	100	100	100	100	66	32	8	0
	1 m	100	100	100	100	92	74	32	0
2 m	0 m	100	100	100	100	68	24	0	0
	1 m	100	100	100	100	100	84	24	0
	2 m	100	100	100	100	100	96	54	2
3 m	0 m	100	100	100	100	82	48	4	0
	1 m	100	100	100	100	98	82	42	0
	2 m	100	100	100	100	100	94	62	4
	3 m	100	100	100	100	100	100	74	10

as distance between antennas increased and antenna installation height decreased. For A type device and without crops, communication performance started to decrease at a distance of 90 m, experienced rapid decreases at 110~120 m, and communication was very weak after that. At antenna height of 0 m, data communication ratio started to decrease at 70~80 m, decreased about 46% at 90~100 m. Best performance was obtained at an antenna height of 3 m with 90~100 m transmission distances (Table 3 and Fig. 3). When there was crop between the transmitting and

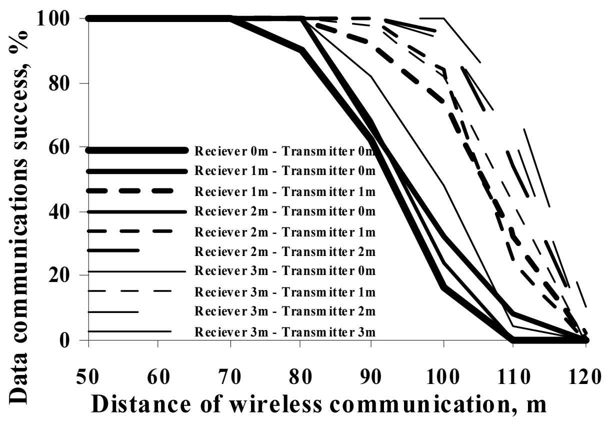

Fig. 3. Communication success ratio at open fields without crop (A type device, %).

Table 4. Communication success ratio at open fields with crop (A type device, %).

Receiver height	Transmitter height	Distance of wireless communication							
		50m	60m	70m	80m	90m	100m	110m	120m
0 m	0 m	100	100	100	88	24	0	0	0
1 m	0 m	100	100	100	94	56	2	0	0
	1 m	100	100	100	98	84	58	12	0
2 m	0 m	100	100	100	100	68	12	0	0
	1 m	100	100	100	100	94	64	22	0
	2 m	100	100	100	100	100	82	52	0
3 m	0 m	100	100	100	100	72	38	0	0
	1 m	100	100	100	100	96	78	24	0
	2 m	100	100	100	100	98	94	48	0
	3 m	100	100	100	100	100	98	62	12

Table 5. Communication success ratio by location in the greenhouse (Transmitter location 2, %).

Receiver height	Transmitter height	Receiver location number			
		1	2	3	4
0 m	0 m	100	90	88	76
1 m	0 m	100	94	92	78
	1 m	100	98	96	92
2 m	0 m	100	100	100	88
	1 m	100	100	100	92
	2 m	100	100	100	98
3 m	0 m	100	100	100	92
	1 m	100	100	100	96
	2 m	100	100	100	100
	3 m	100	100	100	100

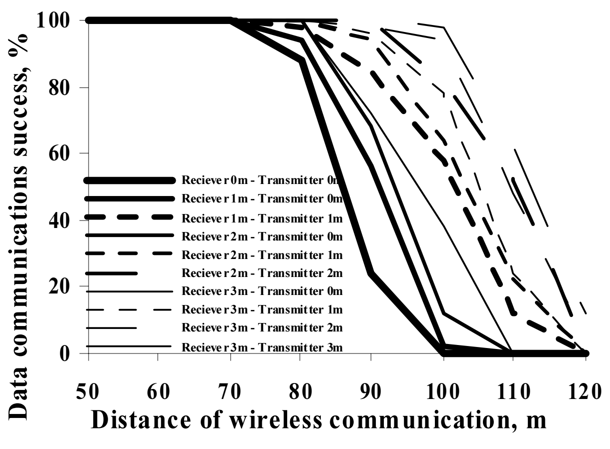

Fig. 4. Communication success ratio at open fields with crop (A type device, %).

receiving antennas, transmission distances were generally shorter than those without crop. At antenna height of 0 m, data transmission success ratio decreased from about 60~70 m, which was 10% less than the distances without crops. When the antennas were installed 2 m above the crop canopy, the communication performance was similar to the case of "no crop" conditions (Table 4 and Fig. 4). B type device showed a good performance up to 60 m, regardless of antenna height and crop presence. However, data communication success ratio was 0% at distances greater than 60 m (data not shown).

2. Evaluation of wireless transmission in greenhouse

For Type A, when data was received at the corner of the greenhouse, transmission success ratios were 100%, except the case that transmitter was located at location "2" (the other corner of the greenhouse; antenna distance of about 90 m) at heights less than the crop height (0 and 1 m) with signal loss of about 10%. When the data was received outside and close to the greenhouse, communication performance was slightly worse than the other case. When the receiver was located at the center of the greenhouse, communication ratios were 100% regardless of the transmitter location and height. For Type B, as at open fields, communication success ratios were 100% at distances less than 60 m and 0% at distances greater than 60 m. Therefore, center of a greenhouse and height greater than crop height was chosen as the best receiver location.

IV. Conclusions

In the study, wireless communication devices were tested at open fields and inside a greenhouse for utilization in protected crop production sites. Major findings were summarized as followings.

- At open fields, data transmission success ratio decreased at distances greater than the manufacturers' specifications. And the performance was worse when there was crop between transmitting and receiving antennas, and when antenna heights were lower than the crop canopy.
- Inside the greenhouse, data transmission success ratio was similar to that at open fields. There was some signal loss when the receiver or transmitter was outside the greenhouse and crops were present between the antennas.

Acknowledgements

This study was carried out with the support of "Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ00740104 2011)", Rural Development Administration, Republic of Korea.

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