Application of smartphone and wi-fi communication for remote monitoring and control of protected crop production environment

Seung-Oh Hur[1], Kyeong-Hwa Han[1], Sang-Ho Jeon[1], Yong-Sun Jang[1], Sin-Woo Kang[2], Sun-Ok Chung[2]*, Hak-Jin Kim[3], Kyeong-Hwan Lee[4]

[1]*National Academy of Agriculture Science, Rural Development Administration, Suwon 441-707, Korea*
[2]*Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon 305-764, Korea*
[3]*Department of Biosystems Engineering, Seoul National University, Seoul 151-742, Korea*
[4]*Department of Rural and Bio-Systems Engineering, Chonnam National University, Gwangju 500-757, Korea*

스마트폰과 Wi－Fi통신을 이용한 시설재배지 환경 원격 모니터링 및 제어

허승오[1] · 한경화[1] · 전상호[1] · 장용선[1] · 강신우[2] · 정선옥[2]* · 김학진[3] · 이경환[4]

[1]농촌진흥청 국립농업과학원 토양비료관리과, [2]충남대학교 바이오시스템기계공학과, [3]서울대학교 바이오시스템공학전공, [4]전남대학교 생물산업기계공학전공

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Abstract : Protected crop production has been popular in Korea as well as in other countries. Intensive and continuous monitoring and control of the environment, which is labor- and time-consuming, is critical for stable crop productivity and profitability, otherwise damage could be happened due to unfavorable ambient and soil conditions. In the study, potential utilization of smartphone and remote access application in protected crop production environment was investigated. Tested available remote access applications provided functions of mouse click (left and right buttons), zooming in and out, and screen size and color resolution control. Wi-Fi data communication speeds were affected by signal intensity and user place. Data speeds at high (> -55 dBm), medium (-70~-56 dBm), and low (< -71 dBm) signal intensity levels were statistically different (α=0.05). Means of data communication speed were 6.642, 4.923, and 2.906 Mbps at hot spot, home, and office, respectively, and the differences were significant at a 0.05 level. Smart phone and remote access application were applied successfully to remote monitoring (inside temperature and humidity, and outside precipitation, temperature, and humidity) and control (window and light on/off) of green house environment. Response times for monitoring and control were less than 1 s at all places for high signal intensity (> -55 dBm), but they were increased to 1 ~ 10 s at home and office and to 10 ~ 30 s at hot spot for low signal intensity (< -71 dBm) for Wi-Fi. Results of the study would provide useful information for farmers to apply these techniques for their crop production.

Key words **:** Smart phone, Remote monitoring, Remote control, Wi-Fi, Greenhouse

I. Introduction

Protected crop production facilities (e.g., greenhouse) have been increased in Korea as well as other countries for better control of cultivation environments (i.e., air and soil conditions) and year-round production of better quality crops. Especially, protected cultivation of leaf and fruit vegetables and flowers are popular in Korea. 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 concentration) affect significantly

***Corresponding author:** Tel: +82-42-821-6712
E-mail address: sochung@cnu.ac.kr

growth, yield, and quality of crops. Adams et al. (2001) investigated effect of different temperature levels (i.e., 14, 18, 22, and 26°C during tomato maturation. After 27 weeks, dry matter contents at temperatures of 18°C (72.0%) and 22°C (75.1%) were greater than those at 14°C (49.4%) and 26°C (29.1%), indicating that a temperature difference of 4°C caused reduction of tomato yield. Marcelis et al. (2004) hypothesized that low light intensity and high temperature could cause reduction of paprika production. Experimental results showed that 33% reduction of light intensity before and after the flowering stage, and 13°C increase of temperature from the normal cultivation temperature (i.e., 20°C) caused 100% of flower drop. Mahajan and Singh (2006) reported that fertigation control in greenhouse increased tomato production by 59.5% and 116.2% compared with the case of greenhouse production without fertigation control and open field cultivation, respectively.

Therefore, monitoring and control of environmental conditions are very important to ensure crop growth, yield, and quality. Otherwise, crops could be damaged considerably due to unfavorable environmental conditions. Jang et al. (2006) implemented environment monitoring and control system and observed cabbage growth. Temperature was monitored and a hot-air heater was turned on when the temperature was less than 5°C. Compared with the uncontrolled condition, this condition increased averaged height and weight by 6 cm and 200 g, respectively. Although it is necessary, on-site environmental monitoring and control is tedious, and labor- and time consuming.

To overcome these limitations of on-site monitoring and control, remote systems have been developed. Remote systems used PDAs (Personal Digital Assistant) or cell phones to communicate through internet or SMS (Short Message Service) (Heo et al, 2002; Lim et al., 2003; Kong et al., 2003; Kim and Hwang, 2003; Shim et al., 2004). Lee et al. (2011) developed a real-time greenhouse environment monitoring system collecting data from sensors for soil temperature, ambient air temperature and humidity, and solar radiation, and web camera, and transmitting them to an internet website. Li et al. (2010) employed a Zigbee-based USN (Ubiquitous Sensor Network) and transmitted the collected information to a GPRS (General Packet Radio Service) module. The GPRS module sent the information to an internet website, enabling remote monitoring of production environment, and also sent warning messages using SMS when necessary. Most of the developed remote monitoring and control systems require lap-top computers accessible to the internet or SMS communication cost.

Recently smart phone are widely spread. One of the features of smart phones is application program that can be used under the Wi-Fi communication environments Wi-Fi communication uses the IEEE 802.11b protocol and provides speeds up to 11 Mbps at 2.4 GHz band. Communication coverage is about 100 m from access point (AP). Communication under Wi-Fi network is influenced by operation conditions such as signal intensity and location of users. Smart phone and application programs provide alternative methods for remote monitoring and control. Recently, alternative methods using smartphone and application software have been developed and employed in medical plant environment, and home networking areas. Examples include monitoring of flow rate (Jeon and Ahn, 2010), control of mobile robot (Ha, 2010), and real time monitoring of heart disease using cardiogram measurement (Oresko et al., 2010). Application of smart phone and application program to agricultural environment may enable more efficient remote monitoring and control. Especially if applications allowing remote access to host computers are used, development of additional application program would not be necessary.

In this study, potential utilization of smartphone and remote access application in protected crop production environment was investigated. Specific objectives were 1) to compare functions and capabilities of commercially available smart phones and remote access applications, 2) to test influence of operation conditions on performance of Wi-Fi communication, and 3) to apply smart phone and remote access application for monitoring and control of greenhouse environment.

II. Materials and methods

1. Concept of remote environment monitoring and control using smart phone

Figure 1 is a diagram showing concept of remote monitoring and control using smart phone and remote access application. Overall system consists of three parts: on-site monitoring and control part, communication service provider, and user part. On-site monitoring and control part includes a computer, on which a remote access server program is installed. User part would access to the on-site computer using remote access application via 3G and Wi-Fi communication network.

To realize the concept, three steps of research were conducted. First, commercially available and wide spread smartphone types (iPhone and Android-based phones) and remote access applications were selected,

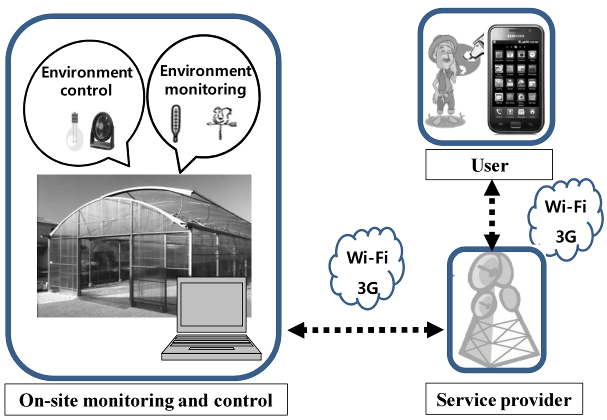

Fig. 1. Schematic diagram showing concept of remote environmental monitoring and control for protected crop production using smartphone and remote access software.

and capability and performance was compared. Second, performance of the selected application software was tested under different conditions (e.g., communication signal intensity). Finally, performance of remote monitoring (inside temperature and humidity, and outside precipitation, temperature, and humidity) and control (window and light on/off) was evaluated with the selected smartphone and application software.

2. Selection of remote access applications

Two sidely used smart phones were selected: Android-OS based and i-OS units. Free and popular remote access applications were selected, and they were referred as R, T, and V, respectively (Table 1). Functions and capability of these applications were compared.

3. Effect of Operation Conditions on Communication Performance

Communication performance was evaluated as data download and upload speeds under different conditions. Data download and upload speeds were measured using an internet speed measurement application (BENCHBEE ver 2.0; Seoul, Korea). Factors affecting the data speed would be signal intensity and location of user. Wi-Fi signal intensity was divided into 3 levels corresponding to number of antenna symbols displayed on the phone (less than −71 dBm, −70 ~ −55 dBm, and greater than −55 dBm). Five measurements were obtained at each signal level, and the means were compared. The experiments were conducted at a university office for about an hour between 20:00 and 21:00.

Even under the same signal intensity, data speeds might be different at different working locations due to different communication devices of the Wi-Fi access points. Therefore, data speeds were also collected at home, university office, and train station (so called Hot Spot) for comparing purpose. For statistical significance of the data speeds under different conditions, t test and Duncan's multiple range test were conducted using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA).

4. Application to monitoring and control of green house environment

Smart phone and remote access application were applied to monitoring and control of green house environment. Monitoring variables were inside temperature and humidity, and outside precipitation, temperature, and humidity, and control variables were window and light on/off. Success ratio (out of 30 trials) and response time of remote monitoring and control were evaluated at different places such as home, university office, and hot spot, and signal intensity levels (greater than −55 dBm, and less than − 71 dBm). Mean response time was classified as 〈 1 s, 1 ~ 10 s, and 10 ~ 30 s.

III. Results and discussion

1. Comparison of remote access applications

Table 1 summarizes major capability of the remote access applications. All of the remote access applications provided mouse click and zooming functions for both Android-OS and i-OS smart phones. Image control capability was different for different applications and smart phone operating systems. For example, T application provided 8 different pixel sizes for Android-OS phones and 3 levels of image quality for i-OS phones. Using V applications, color resolution could be changed, but not pixel size.

2. Effect of communication conditions on data transfer speed

Figure 2 shows data download and upload speeds at different signal intensity for Wi-Fi communication. Error bars indicate ± 1 standard deviations. Download speeds were greater than upload speeds, and the mean values (4.408 and 1.405 Mbps) were significantly different at a 0.05 level. Data speeds increased as signal intensity increased, and the mean values at

Table 1. Comparison of major capability of the selected remote access applications.

		R application	T application	V application
Mouse click		O	O	O
Zoom in/out		O	O	O
Screen control	Android-OS	2-bit colors 8-bit colors 32-bit colors	640 x 480 800 x 600 1024 x 768 1280 x 960 1280 x 1024 1440 x 900 1600 x 900 1680 x 1050	8-bit colors 24-bit colors
	i-OS	640 x 480 800 x 600 1024 x 768 1152 x 864 1280 x 960 1280 x 1024 1440 x 900 1600 x 900 1680 x 1050	High Quality Middle Quality Low Quality	32-bit colors

high (〉 −55 dBm), medium (−70 ~ −56 dBm), and low (〈 −71 dBm) signal intensity levels were statistically different (α=0.05) as they were 4.496, 3.184, and 1.039 Mbps, respectively.

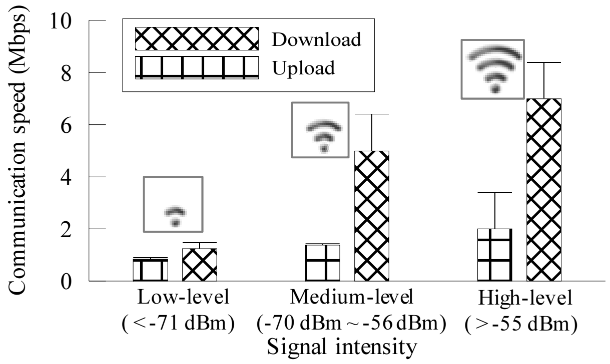

Fig. 2. Data download and upload speeds at different signal intensity under Wi-Fi wireless communication.

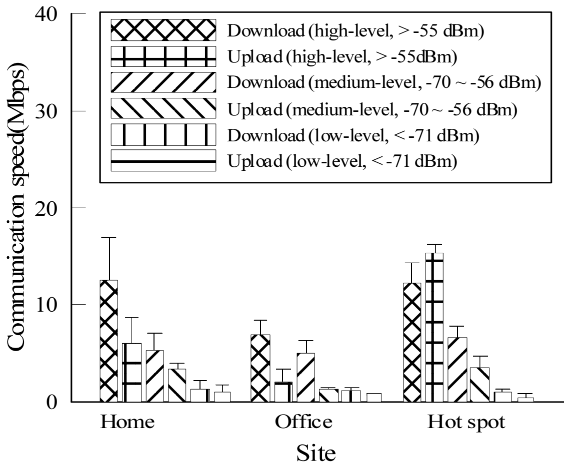

Fig. 3. Wi-Fi data communication speeds by location.

Figure 3 shows Wi-Fi data communication speeds by location and Table 2 summarizes Duncan's multiple mean comparison results. Means of data communication speed were 6.642, 4.923, and 2.906 Mbps at hot spot, home, and office, respectively, and the differences were significant at a 0.05 level. Data speed means were also significantly different by signal intensity and communication direction (down and up), except that the download and upload speeds were not different at hot spot.

3. Monitoring and control of green house environment

Table 3 is the results of greenhouse monitoring and control using Wi-Fi communication at different places and signal intensity. Remote monitoring and control was successful for all cases. Response times for monitoring and control were less than 1 s at all places for high signal intensity (〉 −55 dBm), but they were increased to 1 ~ 10 s at home and office, and to 10 ~ 30 s at hot spot, for low signal intensity (〈 −71 dBm).

Table 2. Wi-Fi data communication speeds (Mbps) by location and signal intensity.

	Hot spot	Home	Office
Total	6.642 (a*)	4.923 (b)	2.906 (c)
By signal intensity			
Low	0.772 (a_c)	1.17 (b_c)	1.039 (c_c)
Medium	5.053 (a_b)	4.35 (b_b)	3.184 (c_b)
High	14.100 (a_a)	9.25 (b_a)	4.496 (c_a)
By download and upload			
Down	6.863 (a_a)	6.398 (b_a)	4.408 (c_a)
Up	6.421 (a_a)	3.448 (b_b)	1.405 (c_b)

* Same alphabet indicates no significant difference among the means

Table 3. Results of greenhouse monitoring and control using Wi-Fi communication (30 trials each; left: >-55 dBm, right: <-71 dBm).

	Home	Office	Hot spot
No. of success	30, 30	30, 30	30, 30
Response time	A, B	A, B	A, C

IV. Conclusions

Potential of remote monitoring and control of protected crop production environment using smart phone and application program was investigated. First, commercially available popular smart phones and remote access applications were compared. Then, data communication speed was tested at different conditions. Finally, smart phone and remote access application were applied to remote monitoring and control of greenhouse environment and the performance was evaluated. Major findings were summarized as followings.

1. Tested remote access applications provided functions of mouse click (left and right buttons), zooming in and out. Screen size and color resolution could be controlled with different degrees of variety.
2. Data communication speeds were affected by signal intensity and user location. They increased as signal intensity increased. Data speeds at high (〉 −55 dBm), medium (−70 ~ −56 dBm), and low (〈 −71 dBm) signal intensity levels were statistically different (α=0.05) as they were 4.496, 3.184, and 1.039 Mbps, respectively.
3. When smart phone and remote access application were applied to remote monitoring and control of green house environment, remote monitoring and control was successful. Response times for monitoring and control were less than 1 s at all places for high signal intensity (〉 −55 dBm), but they were increased to 1 ~ 10 s at home and office and to 10 ~ 30 s at hot spot for low signal intensity (〈 −71 dBm).

Remote monitoring and control of crop production environment using smartphone would be tested under also 3G communication conditions in future study. Results of the study would provide useful information for farmers to apply these techniques for their crop production.

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References

Adams SR, Cockshull KE, Cave CRJ. 2001. Effect of temperature on the growth and development of tomato fruits. Annals of Botany 88: 869-877.

Ha SE. 2010. Remote measurement of digital flow metering using handheld device. Proceedings of Information & Telecommunication Facilities Engineering Spring Conference : 40-41. [in Korean]

Heo WS, Shim JH, Lee SG, Kim KW, Cho MW, Kim HT. 2002. Development of web-based control system for greenhouse teleoperation. Journal of Korean Society for Agricultural Machinery 27(4): 349-354. [in Korean]

Jang SC, Ham SI, Hwang YJ, Na IM, Yoon KP, Lee YJ, Lee JK, Jung BM. 2006. RFID/USN-based cultivation monitoring system. *Proceedings of Korean Institute of Industrial Engineers & Korean Academic Society of Business Administration 2006 Spring Conference* 29(1): 1264-1271. [in Korean]

Jeon YH, Ahn HS. 2010. Smartphone based interface for mobile robot control. *Proceedings of Electronics Engineers of Korea 2010 Spring Conference* 33(1): 1951-1953. [in Korean]

KAMICO, KSAM. 2010. *Agricultural Machinery Yearbook Republic of Korea*. Korean Society for Agricultural Machinery, Seoul, Republic of Korea.

Kim SC, Hwang H. 2003. Interface of tele-task operation for automated cultivation of watermelon in greenhouse. Journal of Korean Society for Agricultural Machinery 28(6): 511-516. [in Korean]

Kong DG, Ryu KH, Jin JY. 2003. Development of database for environment and control information in greenhouse. Journal of Korean Society for Agricultural Machinery 28(1): 59-64. [in Korean]

Lee KO, Bae YH, Oh MS, Nakaji K. 2011. Development of a web‑based greenhouse monitoring system using a field server. Journal of the Faculty of Agriculture Kyushu University 56(1): 103-108.

Li XH, Cheng X, Yan K, Gong P. 2010. A monitoring system for vegetable greenhouses based on a wireless sensor network. Sensors 10: 8963-8980.

Lim JH, Ryu KH, Jin JY. 2003. Development of a greenhouse monitoring system using network. Journal of Korean Society for Agricultural Machinery 28(1): 53-58. [in Korean]

Mahajan G, Singh KG. 2006. Response of greenhouse tomato to irrigation and fertigation. Agricultural Water Management 84: 202-206

Marcelis LFM, Heuvelink E, Baan Hofman-Eijer LR, Den Bakker J, Xue LB. 2004. Flower and fruit abortion in sweet pepper in relation to source and sink strength. Journal of Experimental Botany 55: 2261-2268.

Oresko JJ, Jin P, Cheng J, Huang S, Sun YW, Duschl H, Cheng AC. 2010. A wearable smartphone-based platform for real-time cardiovascular disease detection via electrocardiogram processing. IEEE Transactions on Information Technology in Biomedicine 14(3): 734-740

Shim JH, Paek WJ, Park JH, Lee SG. 2004. Development and performance evaluation of a web-based management system for greenhouse teleoperation. Journal of Biosystems Engineering 29(2): 159-166. [in Korean]