Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller

Tung Le Van[1*], Phuc Nguyen Thi[2], Phung Vo Minh[3], Le Do Thi[4], Huynh Le Cong[5], and Tra Nguyen Thi Phuong[6]
[1−4]Faculty of Physics and Nuclear Engineering, Dalat University
Lam Dong Province, Vietnam
[5,6]Department of Education and Training, Vietnam Ministry of Education and Training
Khanh Hoa Province, Vietnam
Email: [1]tunglv@dlu.edu.vn, [2]phucnt@dlu.edu.vn, [3]phungvm@dlu.edu.vn, [4]ledt@dlu.edu.vn, [5]lchuynh.c3ncthanh@khanhhoa.edu.vn, [6]ntptra.c3dtnt@khanhhoa.edu.vn

***Abstract*—Sensors play an essential role in gathering environmental information for greenhouse farming. Wireless sensor network creates and manages links between sensor blocks in the system. As a result, not only various environmental parameters can be collected, but the sensor location can also be flexibly deployed. Sensor blocks require low energy consumption and inexpensive implementation costs with typical operating conditions. The research has built a wireless sensor network based on open Radio Frequency (RF) technology. Each sensor block has a low deployment cost and operates independently via a solar-powered unit. A novel communication protocol is designed for the proposed sensor network. In addition, a greenhouse controller exploiting designed wireless sensor networks is also constructed to evaluate the practicality of the system. Sensor networks developed are intended to be applied to the existing agricultural greenhouses in the surveyed area. The greenhouse is medium-sized, and the system implemented in practice is for vegetable farming. As a result, the controller can connect to the Internet to serve IoT links and applications. Experimental results prove the practicality of sensor blocks and the stability and efficiency of the wireless sensor network. It helps to reduce deployment costs and improve applicability. In addition, the sensor blocks are designed and built with low energy consumption, which can be operated with a small solar power source.**

***Index Terms*—Wireless Sensor Network, Smart Greenhouse Controller, Communication Protocol**

I. Introduction

PRECISION agriculture, or so-called smart agriculture, dates back to the 1990s. With the development of machines and automation, agricultural farming processes have gradually evolved. Then, sensing, automation, and communication technology help to speed up the implementation of precision agriculture. This trend takes place not only in developed countries but also in other countries, such as Vietnam, which is rapidly taking shape. Specifically, in Dalat city, Vietnam, the report shows that more than 6.530 hectares of agricultural land have applied technology in production [1]. In particular, sensor network technology plays a key role in promoting smart agriculture.

Existing smart greenhouse systems tend to use wired sensor blocks. Cable is used to provide power and data transceiving. This situation can lead to limited operating distance during deployment and create an obstacle for farmers while transplanting. Hence, a wireless sensor network can be a solution.

Wireless sensor networks have the advantage of deployment flexibility and device diversity. During the deployment process, the sensor network and the control system must meet two basic requirements: sustainability and applicability. Specifically, the system must ensure continuous operation, flexibility in deployment, energy-saving, low cost, and easy access to users.

Several studies on sensor networks in precision agriculture and greenhouse farming have been deployed with diverse and increasing practical needs. These approaches come in varying degrees, from direct sensor deployment to the use of existing equipment and system development. Each system has its advantages and disadvantages.

In the previous studies, the researchers use premade wireless communication circuits or develop their products based on ZigBee technology. With the advantage of a developed communication protocol, these

Received: April 09, 2021; received in revised form: June 03, 2021; accepted: June 04, 2021; available online: Feb. 07, 2022.
*Corresponding Author

wireless sensor networks can be rapidly deployed. However, when using the existing ZigBee standard network protocol, the sensor blocks require a lot of hardware resources [2–5]. At the same time, according to a research [2], the direct visibility and penetration ability of the transmitting waves are limited. When deployed in various greenhouse conditions, the central control unit can be out of sight and shielded, leading to difficulties in building hardware infrastructure. In addition, when the network and protocol parameters have been fixed, the users must follow them correctly. This situation reduces the scalability and flexibility of the network configuration.

Previous researchers also use Wi-Fi and GPRS (3G) technology to deploy the sensor network [6, 7] or bridging data to the Internet [8]. The biggest advantage of sensor networks with these two technologies is the ability to connect to the Internet. Each sensor network becomes a subnet, and the sensor parameter values are connected and transmitted directly to the central unit or server. However, the power consumption of the equipment becomes a major obstacle. Large capacity consumption leads to higher investment in the block and reduces practicality. This disadvantage makes wireless sensor networks using Wi-Fi and GPRS difficult to apply. In addition, areas where greenhouses are built with the requirement of independent operation, are also not feasible to apply Wi-Fi or GPRS technology [9].

Another wireless technology that can be used is LoRa and its network, LoRaWAN. In the previous studies [10–12], this technology has been applied because of its advantages of energy-saving, long-distance, and low cost. However, the biggest hurdles of the LoRa technology are low bandwidth and high latency. With small sensor networks, few components, and not requiring large amounts of information, LoRa is a perfect fit. However, with sensor networks requiring many sensor blocks and high information, LoRa cannot respond. In addition, the gateway or central unit for the sensor network using LoRa is complex and requires high investment costs. Therefore, LoRa technology is only suitable for building wide area and long-range and low-bandwidth networks.

A different method in building sensor networks is to use open RF technology [13], specifically the NRF2401 component with a frequency of 2.4 GHz [14, 15]. The open RF technology side can meet the sensor network criteria with low power consumption and consistent bandwidth, which is higher than LoRa technology. Hence, using a sensor network based on open RF technology enables communication with a multi-sensor network and low cost. However, the use of this technology has the disadvantage that no standard communication protocol exists. So, the previous researchers have built the sensor network but do not specify the protocol used [13–15]. This situation makes it challenging to apply it in real scenarios. In addition, the device used in the research also has limits on penetration and coverage because of using the same frequency band as Wi-Fi.

Aiming to design and implement a wireless sensor network for greenhouse farming, the researchers concentrate on the practical aspect of the system. It should have characteristics such as longer-range communication ability, low power consumption, Internet link capability, inexpensive cost, and easy-to-deploy system. These properties are suitable not only for farmers in a remote rural area but also for many existing greenhouse farming systems.

From the analysis, finally open RF technology is chosen to take advantage of the low power, bandwidth, and cost. At the same time, the selected device is Si4463 with 433 MHz, operating frequency band similar to LoRa, replacing 2.4 GHz of NRF2401. At the 433 MHz frequency band, the range of the sensor network is larger, the ability to operate under many obstructions is better, the bandwidth is consistent, and the energy consumption is low [16]. To deploy the sensor network according to the practical requirements, the researchers have developed a standard communication protocol that comes with the greenhouse control system.

II. System Design and Implementation

Sensor networks developed in the research are intended to be applied to existing agricultural greenhouses in the surveyed area. The greenhouse is medium-sized, and the system implemented in practice is for vegetable farming. However, this condition should not be a limitation for implementation as it can be used for many operating greenhouses.

A. *Wireless Sensor Network*

Existing greenhouse characteristics are considered for the construction of sensor networks. The distance and environmental uniformity factors determine the network configuration. Greenhouses often have an even distribution of crops, so the transmission path is not abnormally shielded. In addition, the greenhouse management office is often built near the greenhouse. In other words, the visibility from the control center to the sensing units is similar. With such a feature, a peer-to-peer network with a star topology is suitable. All sensor blocks are directly connected to the central system, as shown in Fig. 1.

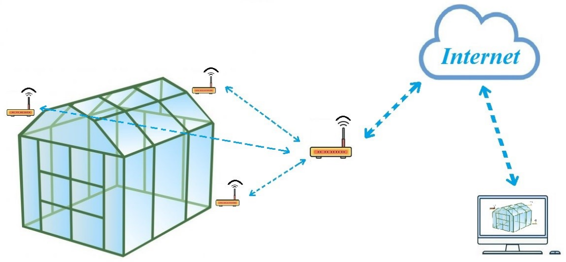

Fig. 1. Proposed wireless sensor network configuration.

The sensor network is designed not only to function independently but also to expand functionality to serve IoT links. Therefore, the control center with Internet connectivity is also implemented. With the sensor network established, the researchers design and build a communication protocol to collect sensory information.

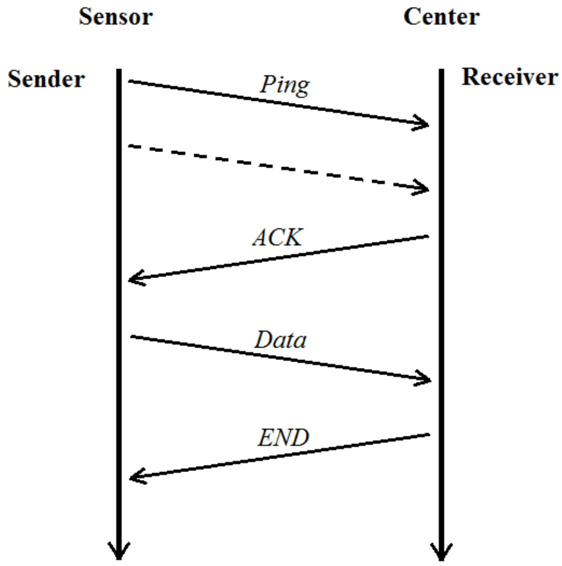

Fig. 2. Proposed handshake protocol.

B. Communication Protocol

The communication protocol is built on resource-limited hardware with the system requirements to save energy and minimize costs. Therefore, the protocol must ensure low computational complexity. Moreover, according to a combination of fact factors and a survey [17], the placement and number of sensors depend on the crop. Therefore, the communication protocol will serve a not too large number of sensors and fewer fluctuations over time. Based on the requirements and parameters presented, the researchers find that the communication protocol implemented by Time Division Multiple Access (TDMA) technique is suitable.

In the traditional TDMA technique, the central system actively divides the access frame and operates according to the master-servant model. Therefore, the researchers have made technical improvements in the direction of reducing the centralized system's computation level. In this design, the sensor blocks actively construct the link with the center block and maintain the assigned timeframe. At the same time, each sensor block will be assigned a different identifier. This identifier helps the control center to manage the quantity and type of sensory information.

It can be seen that if the number of sensor blocks in the network increases, the waiting time between each sensor block with the center can increase accordingly. However, the number of sensor blocks in the network is limited according to actual requirements and little change. At the same time, the communication time between the sensor blocks and the center block is very short compared to the rest time. In this particular example, assuming a greenhouse requires updating sensor data every minute, the sensor network can hold up to six sensor blocks, with each sensor block requiring ten seconds to link and transmit. Therefore, a sensor network implementing the modified TDMA protocol can ensure the greenhouse control system operates stably.

To increase the durability and reliability of communication between the sensor and center units, the researchers implement a "handshake protocol" between these two units. Figure 2 illustrates the fundamentals of handshake protocol. Sensor block actively transmits signaling link "Ping". If the first one fails, the sensor block will wait as long as the communication time interval. Then, it will send the next link signal. After receiving the message, the control center will respond with "ACK", and two blocks will communicate. At the end of the process, the control center will make a signal with the signal "END". By adopting the handshake protocol, the control center will ensure to maintain the link with the sensor block that requires communication. Through the identifier (ID) of the sensor block, the center block can determine the type of information the sensor receives. From there, it will ensure that information is correctly acquired.

At the initial time, the sensor blocks can be activated randomly. Two or more sensor blocks may require linkage with the center unit simultaneously. To avoid communication interference and collisions, the center unit prioritizes interconnecting and communicating with the sensor unit with a lower identifier or earlier message reception.

After the communication is finished, the sensor

Cite this article as: T. L. Van, P. N. Thi, P. V. Minh, L. D. Thi, H. L. Cong, and T. N. T. Phuong, “Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller”, CommIT Journal 16(1), 1–8, 2022.

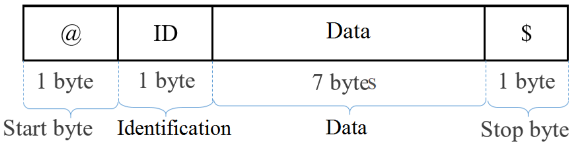

Fig. 3. Data frame.

block will perform the energy-saving function. As it is well known, the interval for sensory data reading and transmission is short compared to the time it waits between two consecutive data sending. After the communication process, the sensor block will be put into a state of “sleep” to lower energy consumption. The amount of sleep depends on the system requirements. Usually, it can last up to a few minutes. Thanks to this sleep process, the design of the power source for the sensor block will be simplified, so it reduces costs.

C. Data Frame

The sensor block transmits using only a certain data frame consisting of 10 bytes, as shown in Fig. 3, to ensure uniform communication time and prevent communication conflicts. The data frame consists of four elements. There are data frame start symbol, identifier, data to be transmitted, and data frame termination symbol.

One byte is used to symbolize the beginning of the data frame. The central block will only process the information when it receives a start symbol. Immediately after the start symbol is a one-byte identifier, it will be stored by the control center to compare with the data obtained after the end of the communication. A group of seven bytes is used to store the sensor values and reserved bytes. These reserved bytes are assigned blank value “null”. In the case of a signal, a character string, such as “Ping”, “ACK”, or “END”, is used. Finally, one byte marks the end of the data frame.

D. Hardware Design and Realization of Sensor Blocks

The sensor block is divided into two types. One is the air sensor, and the other is the soil sensor. Sensor blocks are responsible for measuring important environmental parameters, often of interest in the greenhouse. The air sensor is suspended high and responsible for measuring environmental parameters, such as air temperature, air humidity, and intensity of illumination. Meanwhile, the soil sensor is responsible for measuring grow substrate moisture and temperature. Figure 4 shows the block diagram of the sensor units. The researchers use two air sensors and two soil sensors in the experiment. The identifier of each

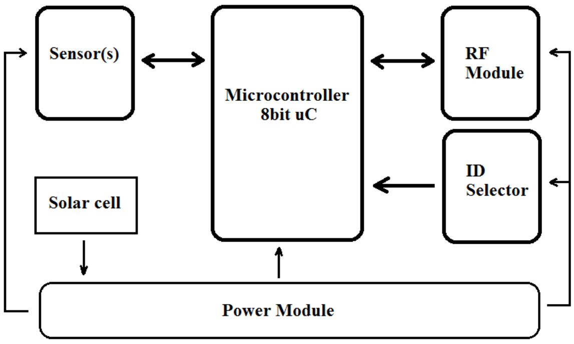

Fig. 4. Block diagram of sensor block.

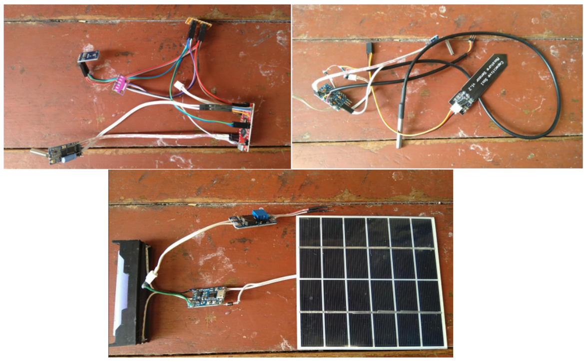

Fig. 5. Hardware testbeds.

sensor block is carried out by four binary DIP switches. Thus, the sensor network can recognize 16 independent sensor blocks.

The central component of the sensor block is the ATmega328 microcontroller with 32 kB of program memory. With the goal of saving energy, the microcontroller operates at a low voltage of 3.3 V and clocked at 8 MHz. In addition, ATmega328 also supports the sleep function to reduce energy consumption between transmissions. The microcontroller also provides standard communication ports. Thereby, it enhances the ability to link with different types of sensors.

In addition, the selected sensors are low energy consumption types. Specifically, the researchers use the BME280 sensor to collect environmental parameters, including air temperature and humidity. BH1750 sensor is used to measure light intensity. With soil sensor block, temperature sensor DS18B20 and capacitive humidity sensor LDTR-WG0236 are used. Figure 5 shows the test circuits and power blocks using the solar cell.

The most important component of the sensor blocks is the wireless communication circuit, RF module, using the Si4463 device. The communication circuit is fabricated with the code name HC12. The HC12

Cite this article as: T. L. Van, P. N. Thi, P. V. Minh, L. D. Thi, H. L. Cong, and T. N. T. Phuong, "Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller", CommIT Journal 16(1), 1–8, 2022.

Fig. 6. Sensor blocks in testing.

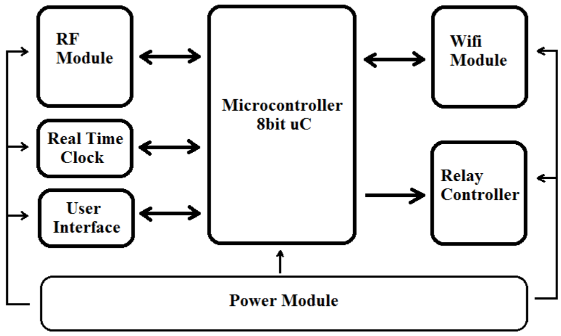

Fig. 7. Block diagram of the main controller.

circuit contains an STM8S003FS microcontroller that simplifies the process of linking with the microcontroller at the sensor block center. Thus, the central microcontroller will link with HC12 through standard Universal Synchronous/Asynchronous Receiver/Transmitter (USART) communication. The HC12 circuit is used with a standard FU3 configuration, channel 1.

The last element in the sensor block is the power module. Because of the wireless network, the sensor units must be able to operate independently. The researchers use solar cells in combination with power banks to power the activity sensor block. The power is designed to ensure the sensor unit's operability even on rainy days.

After testing in the laboratory, the researchers conduct a practical experiment in a greenhouse at Dalat University. The greenhouse has an area of 500 m^2. Currently, it has two systems of sprinkler irrigation and drip of Netafim. Then, its current configuration has only one sensor block linked to the central block via cable. Figure 6 shows the wireless sensor blocks in the research mounted in different locations. Because of the practical use, the sensor blocks have been placed in the protective box.

E. Control Center

To demonstrate the efficiency and practicality of the designed sensor network, the researchers built a control center. It can be seen as the main controller and is equipped with components including sensor network communication block, central processing unit, Internet link block, user communication block, and electricity utilization controller block. Figure 7 illustrates the control center with all modules connected.

The central processing unit exploits the ATmega2560 hardware resources to monitor all aspects of the system. Sensor network communication block, RF module, is responsible for monitoring the wireless sensor network. It is implemented by an ATmega328 microcontroller and HC12 module. Meanwhile, an Internet link block, realized by Wi-Fi module, is responsible for connecting to a webserver to store sensory information. It is an open feature that enables the system to be further improved in the future. Other blocks join the system to make it suitable for practical applications.

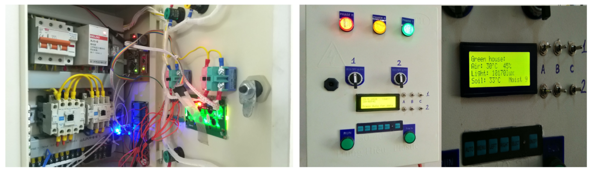

Fig. 8. Installed greenhouse controller in operation.

In the experiment, the researchers focus on the main aspects that are collecting data from the sensor network and processing and storing collected information. Controlling greenhouse equipment is an extra function and can be used to justify the system when necessary. Figure 8 shows the installed and operational full-featured controller.

III. Results and Discussion

The number of sensors selected in the test is four blocks. The two blocks are actually deployed, as shown in Fig 6. The remaining two blocks do not have a protective box and are deployed in the operator house as the reference blocks. This setup scenario is sufficient in most medium to large-sized greenhouses. The distance from sensor blocks to the controller is approximately 100 m. Then, the main controller is located in the operator house with concrete walls. Practical aspects, such as power consumption of wireless sensor block, network establishing, network maintenance, and robustness of control center, are examined thoroughly.

Cite this article as: T. L. Van, P. N. Thi, P. V. Minh, L. D. Thi, H. L. Cong, and T. N. T. Phuong, “Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller”, CommIT Journal 16(1), 1–8, 2022.

TABLE I
POWER CONSUMPTION MEASUREMENTS.

Device	Designation Consumption (mW)	Minimum Consumption (mW)	Air Sensor Block	Soil Sensor Block
Atmega328	10.0	0.01	Installed	Installed
BME280	3.3	0.01	Installed	Not installed
BH1750	0.6	0.01	Installed	Not installed
DS18B20	3.3	3.30	Not installed	Installed
LDTR-WG0236	16.5	16.50	Not installed	Installed
HC12	330.0	52.50	Installed	Installed
Total (mW)			52.5 ÷ 343.9	72.3 ÷ 359.8

A. Sensor Block

Sensor block depends on solar power to operate continuously and wirelessly. Hence, it has to use as little power as possible. Table I shows the theoretical power consumption of the components of each sensor block. The rated power consumption is calculated when the equipment is operating normally at 3.3 V. Meanwhile, the current consumed is minimal when the components are put into an energy-saving sleep state. The RF transceiver can be found to consume the most energy. However, the transmission time is limited. In the research, the sensory data reading and communication time between the sensor block and the center unit are only 10 seconds. After that, the sensor block is put into a sleep state for 60 seconds. Therefore, the average power consumption of the sensor blocks is only about 115 mW.

According to the calculations, the power block uses a Li-ion 18650 backup battery with a capacity of 1000 mAh, which is enough for the system to operate for 28 hours without recharging. The sensor block is attached to a 6 V and 1 W solar panel. It is enough to charge the battery in 7 hours fully. In fact, the sensor block consumes more power than calculation. It happens because some of the sensor block’s auxiliary components also consume electricity. In addition, the current consumption of the component is theoretically lower than it actually is. Therefore, the designed power unit only provides the power for 22 hours of continuous operation without recharging. However, the system still ensures continuous operation with the help of solar cells during the daytime.

B. Sensor Network

The sensor network in deployment is tested for its practicality through two factors. It is network establishing, setup time for specific, and network stability after setup. The first factor is network setup time that is tested in two ways, one being the sequential sensor blocks joining the network and the other being random. First of all, the sequence sensor blocks are activated according to the identifier, so the central and sensor blocks are easy to recognize and communicate. Then, transmitting one signal between the sensor block and the center unit takes about two seconds. This value cannot be adjusted depending on the pre-designed processor on the HC12 circuit. Thus, the total time to read sensory data and transmit all the signals is about 10 seconds. After this time, another sensor block is activated to join the network. After communication, the sensor block performs energy-saving sleep for two minutes. The sensor network remains stable with these four sensor blocks because there is no communication time conflict.

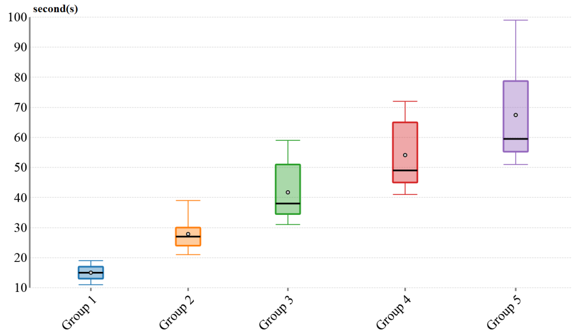

Fig. 9. Network establishment time.

In reality, however, the sensor network is formed in a second way. Sensor blocks join the network at random. Cases can occur, such as users changing sensor placement, increasing or decreasing the number of sensor blocks in the network, or any unexpected problem. Figure 9 shows the measured results with an increasing number of sensor groups. Group 1 has only one sensor block and the sensor network communication block at the main controller. Meanwhile, Group 2 has two sensor blocks and the controller, and so on. Since the number of sensors is small and the waiting time between two consecutive data updates is large, the average time is measured in seconds (s).

It can be seen that the best time is achieved when the next sensor is activated almost immediately after the first sensor. Therefore, it just has to wait for the first sensor to link and transmit data. Conversely, the

Cite this article as: T. L. Van, P. N. Thi, P. V. Minh, L. D. Thi, H. L. Cong, and T. N. T. Phuong, "Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller", CommIT Journal 16(1), 1–8, 2022.

longest time occurs when the next sensor is activated when the previous sensor is transmitting data and is about to terminate. Thus, the network setup time will fall between these two extreme points. During the experiment, the researchers find that the randomness of the sensor activation produced is evenly distributed, and the network setup time tends to increase linearly with the number of sensor blocks.

The second factor is the stability of the sensor network. The researchers configure the system to get only one environmental parameter value per sensor block. Thus, the obtained value of each sensor block will be in its range. Deviation in value will be an indication of error or interference. At the same time, the main controller is connected to the Internet through the Internet link block via the ESP8266 device. All data are sent to the chosen web server, Thingspeak. The results obtained during the experiment show the stability of the wireless sensor network, namely the communication protocol during operation. Figure 10 shows the time correlation of the two most important greenhouse parameters: temperature and humidity. It is noticed that fluctuations occur in environmental parameters in greenhouses from day to day. With such data, the greenhouse operator or farmer can proactively adjust the equipment in the greenhouse to suit the farming requirements of each crop.

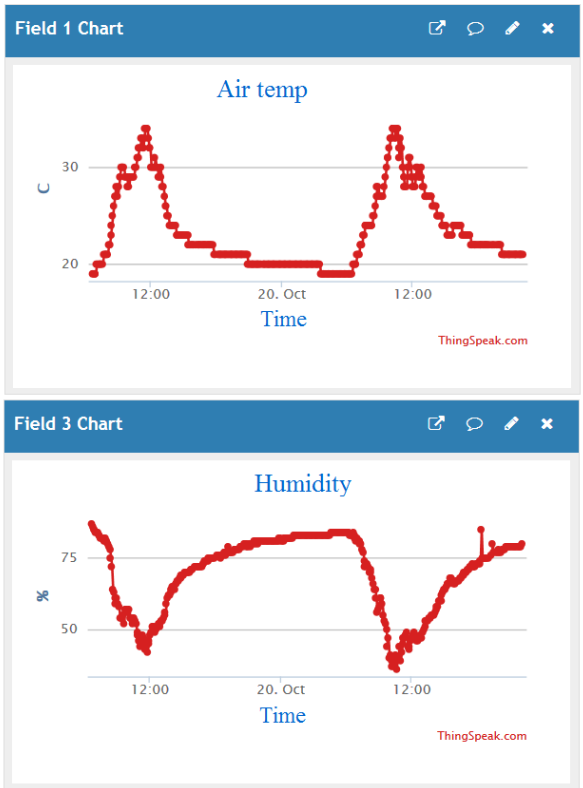

Fig. 10. Data display on a webserver.

C. Control Center

After testing sensor blocks and networks, the control center is also checked for its long-term operating robustness. The greenhouse is used by the faculty for growing tomatoes. During three months of testing, the control center is tested in three operation modes, time equivalence, and sequentially. The first mode is manual control. Depending on the environmental values provided by sensor blocks, the operator controls the greenhouse's equipment, water pump, and circulating fan by manually turning them on and off accordingly. The second mode is scheduled time control. The operator sets the on and off time for devices based on a predefined timetable with the aid of the control center's real-time clock. Finally, the third mode is fully automatic control. Devices are controlled based on plant requirements, such as temperature and humidity preset thresholds. Greenhouse operator constantly monitors the growth of plants to ensure they follow development requirements. After finishing the field test, the control center shows its stability and proves to be robust in practical working conditions.

IV. Conclusion

The wireless sensor network not only helps to monitor the environmental parameters but also provides information to assist the farmer in making the right adjustment decisions. The researchers have built two types of sensor blocks, soil sensor, and air sensor, for gathering needed information. The researchers have also implemented the main controller for processing data and connecting to a web server. At the same time, a communication protocol for wireless sensor networks is also designed and implemented practically. The communication protocol has low computational complexity and is implemented on sensor blocks with low hardware resources. As a result, it helps to reduce deployment costs and improve applicability. In addition, the sensor blocks are designed and built with low energy consumption, which can be operated with a small solar power source. The practical results have proven the practical applicability of the research. However, as the researchers increase the number of sensor blocks, delay is also introduced into the communication system. Each sensor block has to wait for its turn to transmit data to the control center.

In future research, more work is needed to apply and test the capability of the wireless sensor network with a large amount of sensor blocks. In addition, other practical aspects should be investigated to put the system in the field for the daily use of farmers.

Cite this article as: T. L. Van, P. N. Thi, P. V. Minh, L. D. Thi, H. L. Cong, and T. N. T. Phuong, “Design and Implementation of a Wireless Sensor Network for Smart Greenhouse Controller”, CommIT Journal 16(1), 1–8, 2022.

ACKNOWLEDGEMENT

The research team would like to thank the Faculty of Agriculture and Forestry, Dalat University, Vietnam, for helping in the process of testing the system at the greenhouse.

REFERENCES

[1] Cuc Thong Ke Tinh Lam Dong, “Report on countryside development 2019 of Dalat city, Vietnam,” 2019. [Online]. Available: http://cucthongke.lamdong.gov.vn/Default.aspx

[2] T. Ahonen, R. Virrankoski, and M. Elmusrati, “Greenhouse monitoring with wireless sensor network,” in *2008 IEEE/ASME International Conference on Mechtronic and Embedded Systems and Applications*. Beijing, China: IEEE, Oct. 12–15, 2008, pp. 403–408.

[3] M. Erazo, D. Rivas, M. Pérez, O. Galarza, V. Bautista, M. Huerta, and J. L. Rojo, “Design and implementation of a wireless sensor network for rose greenhouses monitoring,” in *2015 6th International Conference on Automation, Robotics and Applications (ICARA)*. Queenstown, New Zealand: IEEE, Feb. 17–19, 2015, pp. 256–261.

[4] M. A. Akkaş and R. Sokullu, “An IoT-based greenhouse monitoring system with Micaz motes,” *Procedia Computer Science*, vol. 113, pp. 603–608, 2017.

[5] P. T. Daely, H. T. Reda, G. B. Satrya, J. W. Kim, and S. Y. Shin, “Design of smart LED streetlight system for smart city with web-based management system,” *IEEE Sensors Journal*, vol. 17, no. 18, pp. 6100–6110, 2017.

[6] S. Trilles, A. González-Pérez, and J. Huerta, “A comprehensive IoT node proposal using open hardware. A smart farming use case to monitor vineyards,” *Electronics*, vol. 7, no. 12, pp. 1–31, 2018.

[7] D. X. Quy, L. Q. Hoang, N. D. X. Bach, T. T. Dat, and V. T. Cuong, “Automated greenhouse controller for agriculture using wireless devices,” *Quang Binh Journal of Science and Technology*, pp. 73–77, 2017.

[8] J. López-Martínez, J. L. Blanco-Claraco, J. Pérez-Alonso, and Á. J. Callejón-Ferre, “Distributed network for measuring climatic parameters in heterogeneous environments: Application in a greenhouse,” *Computers and Electronics in Agriculture*, vol. 145, pp. 105–121, 2018.

[9] S. Candy, G. Moore, and P. Freere, “Design and modeling of a greenhouse for a remote region in Nepal,” *Procedia Engineering*, vol. 49, pp. 152–160, 2012.

[10] V. A. Vu, D. C. Trinh, T. C. Truvant, and T. D. Bui, “Design of automatic irrigation system for greenhouse based on LoRa technology,” in *2018 International Conference on Advanced Technologies For Communications (ATC)*. Ho Chi Minh City, Vietnam: IEEE, Oct. 18–20, 2018, pp. 72–77.

[11] Y. Wu, L. Li, M. Li, M. Zhang, H. Sun, N. Sygrimis, and W. Lai, “Remote-control system for greenhouse based on open source hardware,” *IFAC-PapersOnLine*, vol. 52, no. 30, pp. 178–183, 2019.

[12] R. K. Singh, R. Berkvens, and M. Weyn, “Energy efficient wireless communication for IoT enabled greenhouses,” in *2020 International Conference on COMmunication Systems & NETworkS (COMSNETS)*. Bengaluru, India: IEEE, Jan. 7–11, 2020, pp. 885–887.

[13] K. P. Ferentinos, N. Katsoulas, A. Tzounis, T. Bartzanas, and C. Kittas, “Wireless sensor networks for greenhouse climate and plant condition assessment,” *Biosystems Engineering*, vol. 153, pp. 70–81, 2017.

[14] Y. Achour, N. El Mernissi, and D. Zejli, “Design and implementation of greenhouse remote monitor system,” in *2018 IEEE 5th International Congress on Information Science and Technology (CiSt)*. Marrakech, Morocco: IEEE, Oct. 21–27, 2018, pp. 1–6.

[15] C. D. Moreno-Moreno, M. Brox-Jiménez, A. A. Gersnoviez-Milla, M. Márquez-Moyano, M. A. Ortiz-López, and F. J. Quiles-Latorre, “Wireless sensor network for sustainable agriculture,” *Multidisciplinary Digital Publishing Institute Proceedings*, vol. 2, no. 20, pp. 1–4, 2018.

[16] A. Kochhar and N. Kumar, “Wireless sensor networks for greenhouses: An end-to-end review,” *Computers and Electronics in Agriculture*, vol. 163, pp. 1–15, 2019.

[17] C. K. Lee, M. Chung, K.-Y. Shin, Y.-H. Im, and S.-W. Yoon, “A study of the effects of enhanced uniformity control of greenhouse environment variables on crop growth,” *Energies*, vol. 12, no. 9, pp. 1–24, 2019.