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An Integrated Wireless Sensing System for Monitoring Environmental Parameters in Mushroom Houses

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Abstract

The paper presents an integrated wireless sensing system for monitoring environmental parameters, including temperature, relative humidity, and light intensity in mushroom houses. The developed system not only collects spatial environmental data but also enables end-users to remotely observe them via smart devices. Assembly of five sensornodes with a wireless sensor network was used to gather data. The results have shown relatively accurate measurements in terms of environmental parameters. The system is low cost, simple and easy to operate by displaying the native language in interface monitoring software. Therefore, the generated system should be applied in monitoring air temperature, humidity, and light intensity in mushroom houses. Additionally, this study has provided good opportunities for Vietnamese farmers to approach the high technology application in agriculture.

Keywords

Remote monitoring, environmental parameters, wireless sensors network, database, MySQL, PHP

Introduction

The environment is one of the most important factors that significantly influence the development of agricultural crops. Monitoring environmental parameters such as temperature, humidity, and light intensity, etc. has great practical value in agriculture production. Based on the measurements gathered by monitoring systems, these environmental parameters can be adjusted in order to obtain better production yields and minimize the use of resources.

Recently, with the developments in computer science and technology, and measurement and wireless technology, the wired

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monitoring systems are being replaced by wireless monitoring systems, which allow the collection of information to take place without making any physical contact. With the technological developments, the wireless sensors networks (WSNs) have been applied to collect a range of data. WSNs have many benefits such as they are easier to physically deploy, easily scalable, cost effective, and have extended range capability. Therefore, it can be seen that remote sensing is one of the effective technologies to solve the problems of monitoring and control in agriculture that are usually done over large areas. WSNs are widely applied in various agricultural applications, such as monitoring the environment in greenhouses and gardens (Kim *et al.*, 2011), determining organic matter in soil (Linh, 2015), and creating a virtual fence to control cow herds (Butler *et al.*, 2004), etc. In 2017, we suggested a wireless temperature and humidity monitoring system to be used outdoors (Dung, 2017). The system included one sensor node and coordinator, which was able to collect air temperature and air humidity.

In this research, we have developed a low-cost wireless monitoring system. The system was designed to observe environmental parameters in a mushroom growing house via software on a PC and the Internet. To create a system with a low cost, we chose electronic components that are available in Vietnam. In addition, the monitoring interface utilizes Vietnamese language that is easy for farmers to understand. The cost of the developed system is lower than the cost of some commercialized products like Monnit or Libelium wireless sensor networks. Therefore, Vietnamese farmers have more opportunities for high-tech applications in production.

Many studies have shown that the important environmental parameters affecting the growth process and development of fungi are temperature, humidity, light intensity, and CO_2. Temperature affects the activity of the enzymes, thus affecting the metabolism and growth of the fungi (Kiet, 2012). Most fungi need high humidity, but each stage requires different humidity levels. The moisture of the substrate should be about 65 - 70%, which is the optimal condition for the growth and development of mushrooms. The stage of mycelium growth requires air humidity 70 - 75%. To germinate, mushrooms need moisture from 95 to 100%, but when mushrooms reach the mature stage, the humidity need is lower, about 85 - 90%. The composition of the air, especially the concentration of CO_2, has a great influence on the growth of the fungi. A CO_2 concentration of 0.4 - 0.6% will completely inhibit the formation of sporangium. A CO_2 concentration of 0.2 - 0.4% causes long stipes and thin caps. The most appropriate CO_2 concentration for growing sporangium is less than 0.2% (Kiet, 2012). Light seems to have a negative effect on the growth of most fungal species at the nutritional growth stage as light affects the color and shape of sporangium. Light is needed, however, for the development of the mushroom caps. When fungi are transferred to the dark, it stimulates the formation of stipes without stimulating the formation of fungal caps. When a sporangium is formed, it needs diffused light of 100 - 200 lux (Linh *et al.,* 2012). The objectives of this paper were to introduce the structures of the monitoring system in detail and measure the air temperature, air humidity, and light intensity.

Materials and Methods

The overall structure of the system

The wireless monitoring system is illustrated in Figure 1. The system is composed of three major parts: a wireless sensors network (WSN), coordinator node, and computer node.

The WSN was developed for collecting air temperature, air humidity, and light in a remote mushroom growing house. The WSN was in a “star structure” with five sensor nodes and one router. After receiving data from each sensor node, the router sent it to the coordinator node. The coordinator received data from the WSN and transmitted it to the computer. It also obtained commands from the computer and sent them back to the WSN. The computer was used not only for observing, saving, and analyzing data, but was also set up like a server in a web application.

The WSN and coordinator node

In this section, we used theoretical methods to research WSNs and coordinators. The structures of nodes are shown as follows.

The hardware design of terminal sensor node

Figure 2 shows the main parts of the temperature, humidity, and light sensor nodes.

The sensor node included five components: MCU, sensors, transceiver, power source, and display block.

MCU

This system used ATMEGA 8 as the core hardware of the terminal sensor node and coordinator node. Some features of ATMEGA 8 are described as follows:

- 8k byte of flash program memory, 512 bytes EEPROM, 1KB internal SRAM

- 23 programmable I/O lines

- Two 8-bit timer/counter, one 16-bit timer/counter; real time counter; 3 PWM channels; 6 channels ADC in PDIP package; two-wire serial interface; serial USART; master/slave SPI serial interface

- Five sleep modes: idle, ADC noise reduction, power save, power-down, and stand by

- Operating voltage: 4.5 - 5.5 V

This MCU can work normally when powered by low-voltage power sources like a battery supply.

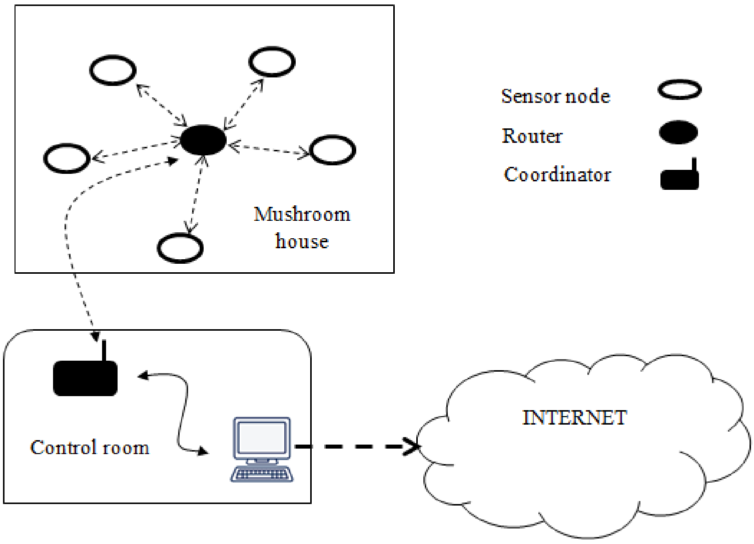


Figure 1. Structure of the wireless monitoring system

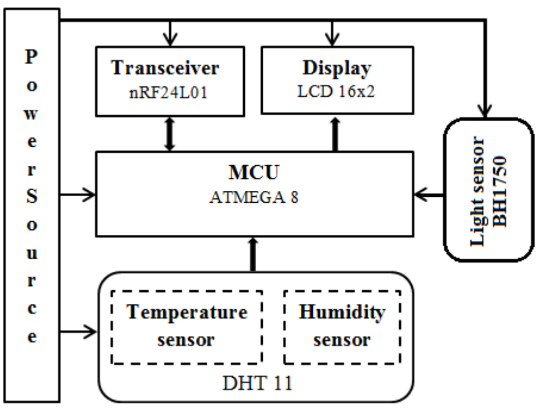


Figure 2. Terminal sensor node structure

Temperature and humidity sensor DHT11

The DHT11 temperature and humidity sensor featured a temperature and humidity sensor complex with a calibrated digital signal +output. This sensor included a resistive-type humidity measurement component and an NTC temperature measurement component. Because of the 8-bit digital signal output, it was connected to a performance 8-bit microcontroller. Technical specifications are shown in Table 1.

DHT11's power supply was 3 - 5.5 VDC. One capacitor valued 100 nF could be added between VDD and GND for power filtering.

Single bus data format was used for communication and synchronization between the MCU and DHT11. A complete data transmission was 40 bits. Data format: 8 bit integral RH data + 8 bit decimal RH data + 8 bit integral T data + 8 bit decimal T data + 8 bit check sum. When the communication between the DHT11 and MCU begins, the MCU will set the data single-bus voltage level from high to low, and this process takes at least 18 ms to ensure the DTH's detection of the MCU's signal, then the MCU will pull up voltage and wait 20 - 40 us for the DHT's responses. Once the DHT detects the start signal, it will send a low-voltage-level response signal, which lasts 80 us. Then, the DHT program sets the data single-bus voltage level from low to high and keeps it for 80 us for the DHT's preparation for sending data. When the DHT is sending data to MCU, every bit of data begins with the 50 us low voltage level, and the length of the high voltage level signal determines whether data bit is "0" or "1". The 26 - 28 us high voltage length means "0", and the 70 us high voltage length means "1". When the last bit data is transmitted, DHT11 pulls down the voltage and keeps it for 50 us. Then, the single bus voltage will be pulled up by the resistor to set it back to free status.

Light sensor BH1750

BH1750FVI is a digital ambient light sensor IC for I2C bus interface. This IC is the most suitable to obtain ambient light data for adjusting LCD and keypad backlight power of mobile phones. This sensor can detect wide range of light data at high resolution (1 - 65535 lux).

Some features of BH1750:

- I2C bus Interface (f/s Mode Support)

- Spectral responsibility is approximately equal to human eye response

- Illuminance to digital converter

- Wide range and high resolution (1 - 65535 lux)

- Low current by power down function

- 50 Hz/60 Hz light noise reject-function

- 1.8 V logic input interface

- Does not need any external parts

- It is possible to select 2 types of I2C slave-address.

- Adjustable measurement results to influence the optical window.

VCC and I2C reference voltage are 2.4 - 3.6 V and 1.65 - VCC, respectively.

nRF24L01

The wireless transmission circuit adopted the wireless transceiver nRF24L01, which is a single chip radio transceiver for worldwide 2.4 - 2.5 GHz ISM band. The transceiver consisted of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, modulator and Enhanced ShockBurst protocol engine. Some features of nRF24L01: on the air data rate 1 - 2 Mbps, digital interface (SPI) speed 0 - 8 Mbps, 125RF channel operation, and power supply range of 1.9 - 3.6 V. The current consumption is very low, only 0.9 mA at an output power of - 6 dBm and 12.3 mA in RX mode. Power saving is easy because of power-down and standby modes.

Table 1. Technical specifications of DHT11

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20 - 90% RH 0 - 50^{o}C	± 5%	± 2^{o}C	1	4 Pin single row

Power supply

Because the working voltage of ATMEGA8, LCD, DHT11, and nRF24L01 is 5 V, 5 V, 5 V, and 3.3 V, respectively, we used a 7805 to steady 5 V and AMS 3.3 to create 3.3 V. The system worked well with a battery or TP link supply.

The hardware design of router and coordinator node

The router is illustrated in Figure 3. It received data from the sensor nodes, and packaged the data before sending the data to the coordinator.

As shown in Figure 4, the coordinator node sent data to the computer and received commands from the computer. In order to communicate between ATMEGA 8 and the computer, this system used the most common RS-232 communication interface. A USB to TTL serial UART cable was used. Each TTL-USB cable contained a small circuit board, which converted TTL level to USB. The cable provided a fast, simple way to connect the devices with a TTL level serial interface to USB.

Packet format

In the WSN, all sensor nodes had their own unique address. To improve the anti-jamming and error performance of the WSN, the addresses of sensor nodes must be significantly different from each other. To enhance the compatibility of the wireless networking, the data returned from one sensor node was indicated by string type and formatted as follows "ID: Temperature: Humidity: Illumination". The string "ID" determined the sensor node. Therefore, data conflict would not occur in data transmission, although all nRFL01s worked in the same frequency band. Data format is shown in Table 2.

The software design of system

The graphical method was used to design the principle circuits, printed circuit boards (PCBs), programmable, and monitoring software. Principle diagrams and PCBs of the system were designed by Proteus software. Code vision AVR compiler was used to program the MCU. Interface monitoring software was designed by Visual Studio.

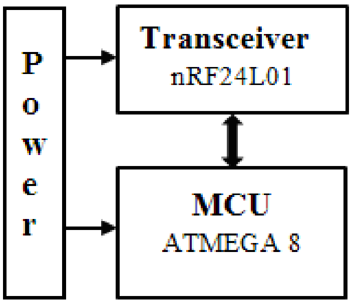


Figure 3. Router node structure

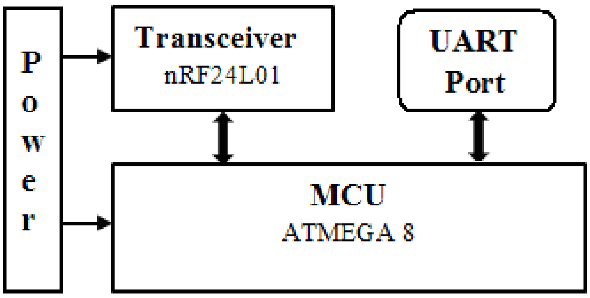


Figure 4. Coordinator node structure

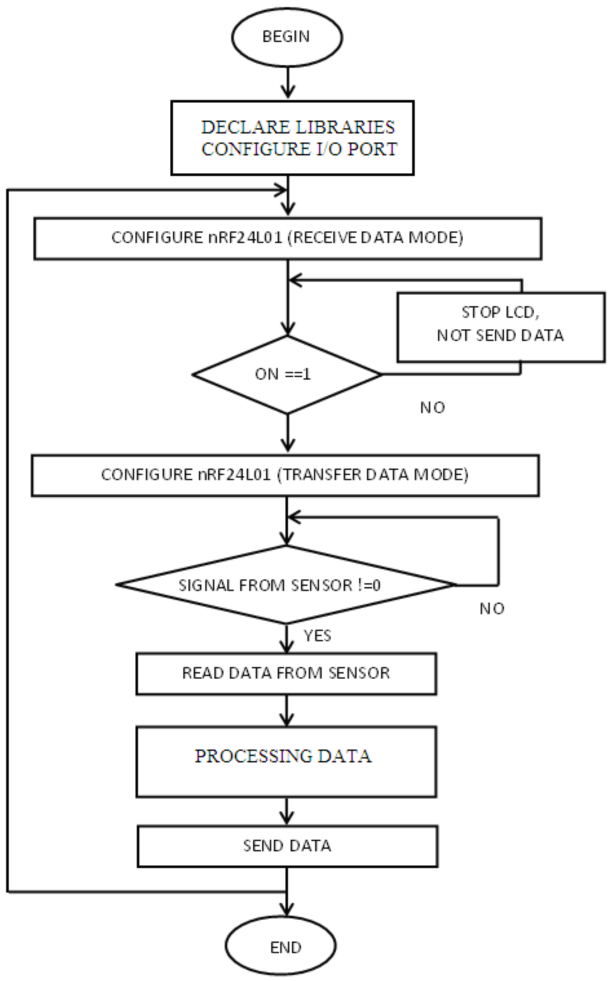


Figure 5. Algorithm flowchart of terminal sensor node

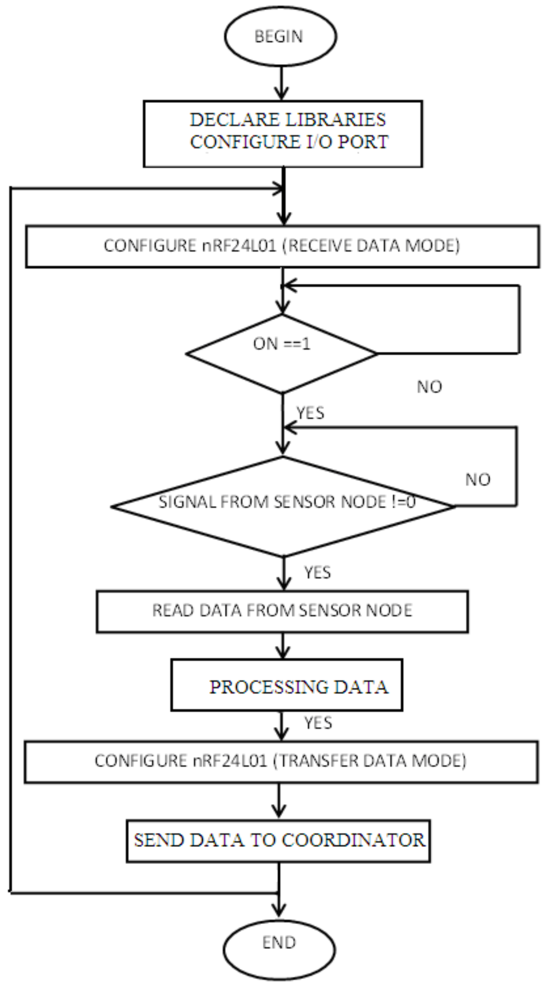


Figure 6. Algorithm flowchart of router node

Table 2. Data format

1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	6 bytes
ID	:	Temperature	:	Humidity	:	Illuminance

The main algorithm flowcharts of the terminal sensor nodes, router node, and coordinator node are illustrated in Figures 5, 6, and 7, respectively.

Principle diagrams of the terminal sensor nodes, router node and coordinator node are shown in Figures 8, 9, and 10, respectively.

Figures 11 and 12 show the WSN and coordinator node designed in the study.

Figure 13 shows the windows of monitoring interface. The software uses Vietnamese, so it is very easy to use.

Developing web application

In this research, we also developed a web application. To set up a web server, a server application, database, and scripting language are needed. In this study, we used XAMPP which is a free and open source cross-platform web server developed by Apache Friends. XAMPP allowed us to configure a local web server (Apache) on our PC for testing. A database (MariaDB) was created to store the collected environmental parameters by WNS (Figure 14). Netbean IDE was used to write scripts in the

PHP programming languages. The website is shown in Figure 15.

Results and Discussion

In this study, two experiments were performed to determine the working distance and accuracy of the WSN. In these experiments, the sensor nodes collected data and transmitted the data to the router with RF 2.4 GHz (radio frequency wave). The data from the router was sent to the coordinator with RF 2.4 GHz, too. The coordinator continued to send data to the PC through the serial port. The serial port was set to COM 4 or 5, the band rate was set to 9600 bps, the data was 8 bits, there was no parity, stop bit was 1 bit.

In the first experiment, we measured temperature, humidity, and light to determine the accuracy of the WSN. Data was measured every 10 min and compared to data received by the standard equipment.

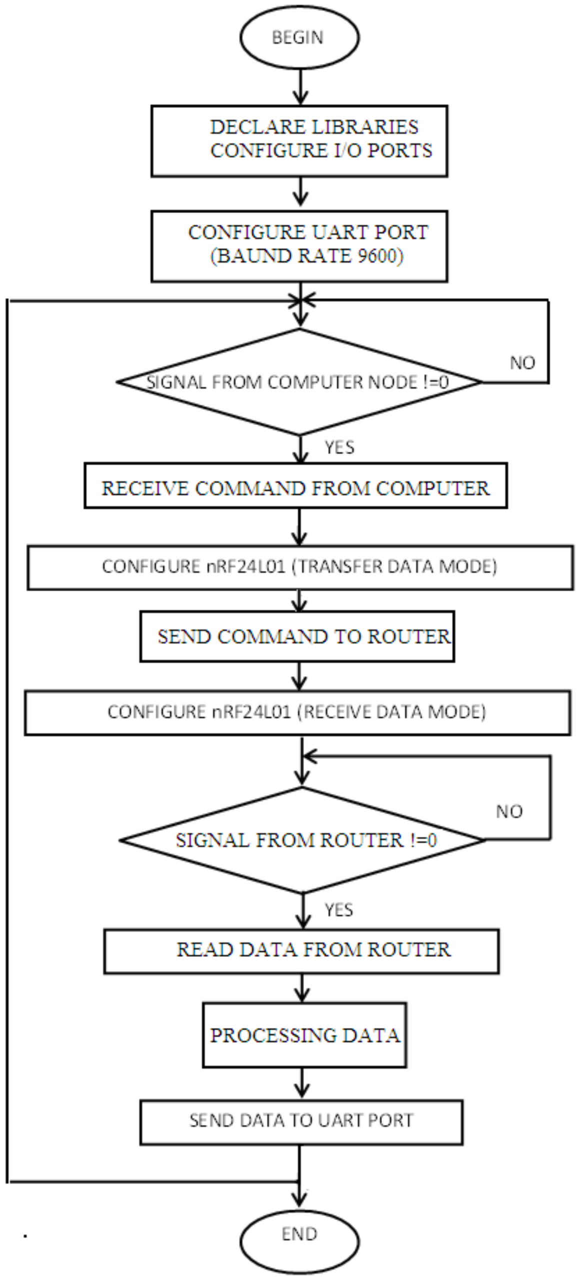


Figure 7. Algorithm flowchart of coordinator

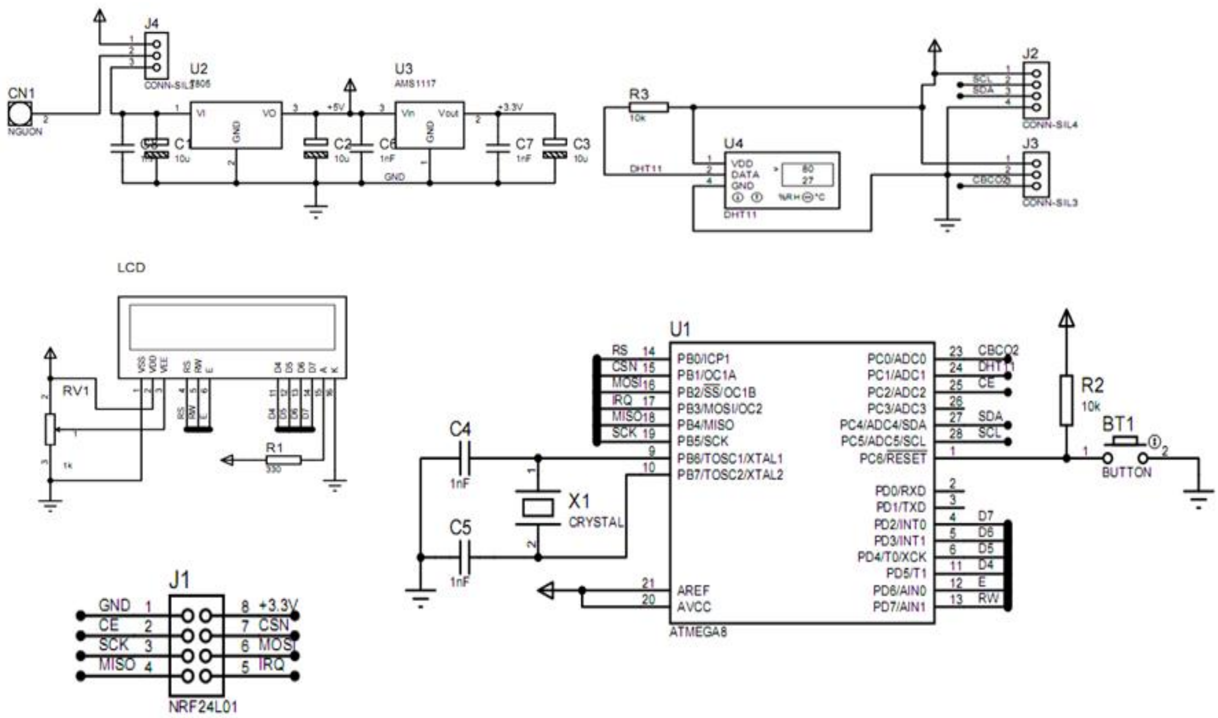


Figure 8. The terminal sensor node principle diagram

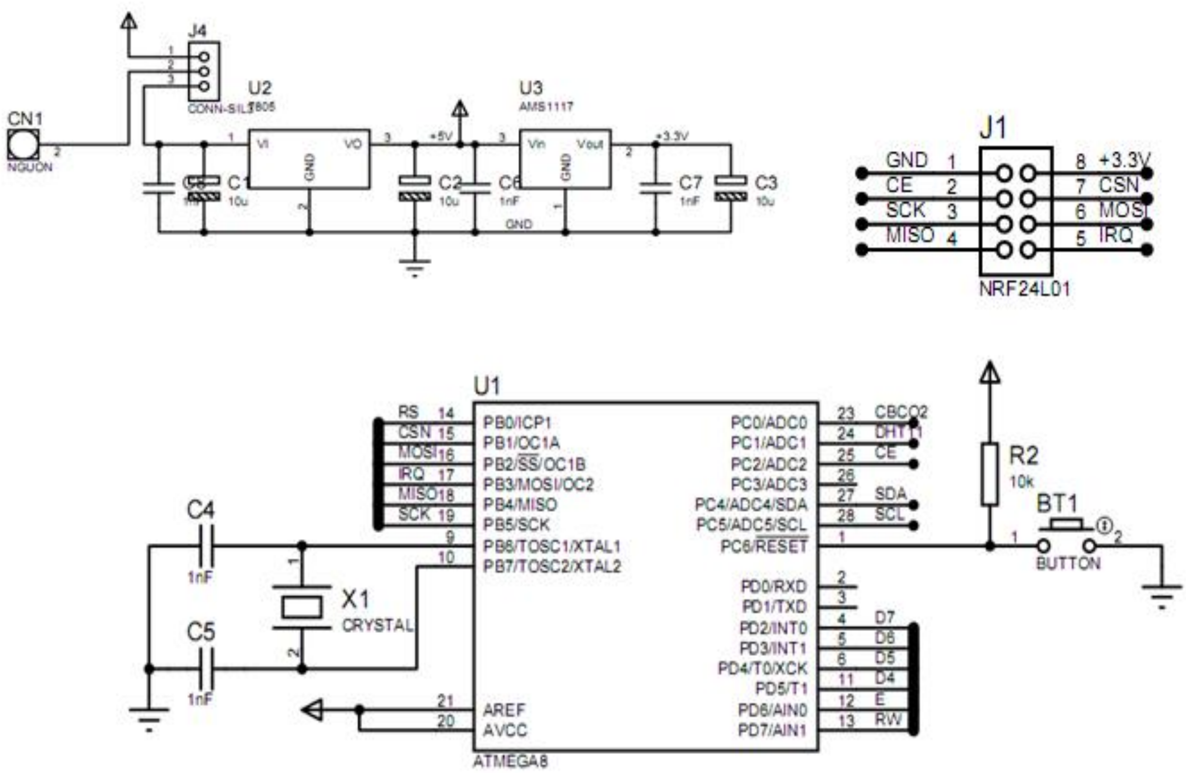


Figure 9. The router node principle diagram

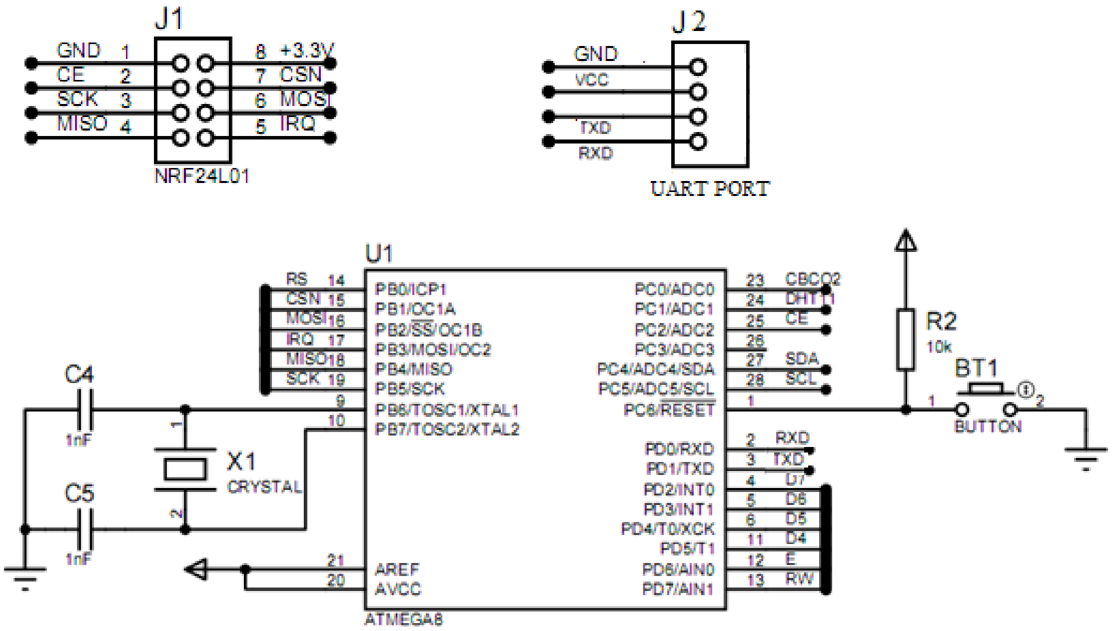


Figure 10. The coordinator node principle diagram

Figure 11. Wireless sensor network

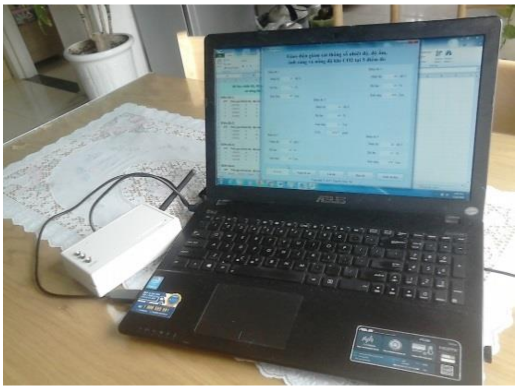


Figure 12. Coordinator connected to a PC

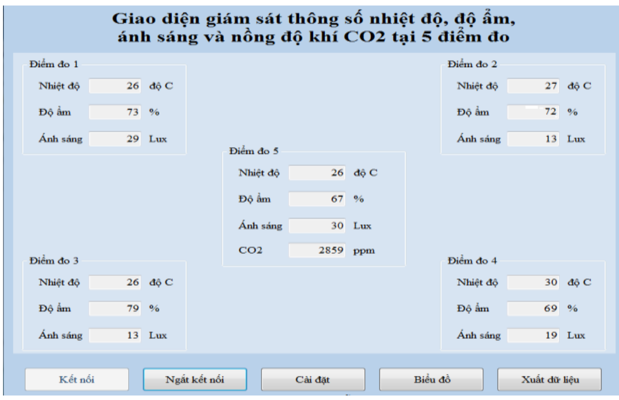


Figure 13. Monitoring interface

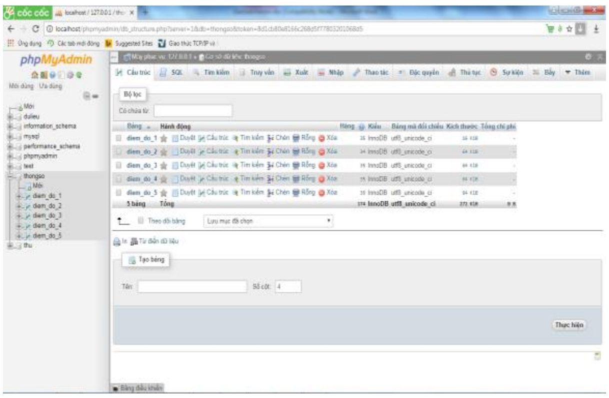
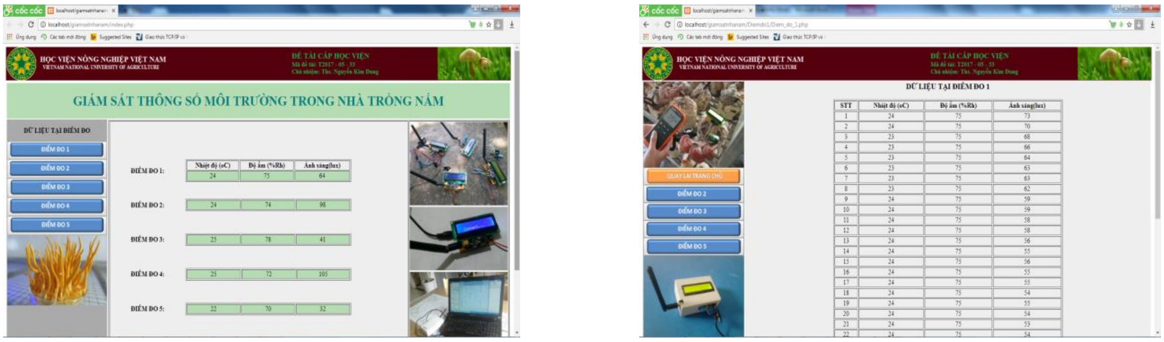


Figure 14. Database illustration



a. Home page of the monitoring website

b. Web page for monitoring data of the first sensor node

Figure 15. Website for monitoring environmental parameters in the growing mushroom house

a. WNS in a mushroom house

b. Standard meter and a sensor node

Figure 16. Experimental measurement in the mushroom growing house

Figure 17. Estimating the illumination error in lab

Themo. Hygrometer of EXTECH and Digital light meter model 5202 of Kyoritsu were used to measure the standards in this test. This experiment was carried out independently for each sensor node. The measured values by the first sensor node are shown in Table 3. Data collected by the other sensor nodes was similar.

In the second experiment, we first put the router of the WNS and the coordinator apart by 5 m. Then we gradually increased the distance between the two devices. The results show that the system works best in a range of 0 to 200 m. Outside this range, no communication signal between the devices was observed.

By comparing the collected data with the standard meters, it can be seen that the measurement results were relatively accurate. Temperature error was less than ± 1.5^{o}C, humidity error was lower than ± 5% RH, and illuminance error was below ± 2 lux (Table 3).

Moreover, this is a low-cost wireless monitoring system. The total cost of the designed system is approximately 600 USD, whereas, a monitoring remote system of Monnit which includes five air temperature, humidity, light sensors, and iMonnit Express software (runs as a standalone PC application without the need for an Internet connection) costs about 1289 USD. By comparing the two systems, it can be seen that the designed system is 50% cheaper than the Monnit system. Therefore, this research increases opportunities of applying high technology in agricultural production for Vietnamese farmers.

Conclusions

In this paper, a wireless system collecting environmental parameters in mushroom growing houses was designed, developed, and tested. From the obtained results, we confirmed that this system can be applied in monitoring temperature, humidity, and light in mushroom growing houses.

However, further research should be focused on some challenges as follows: (i) Prolong lifespan of batteries by using solar cell or wind energy, etc.; (ii) Integrate more sensors into the module. The CO_2 level is also one of the most important parameters in growing mushrooms. Although we have conducted experiments with the MG-811 CO_2 sensor in this study, the measurement output is still unstable; and (iii) Develop an outer layer of the hardware devices that supports the system to work properly under harsh environmental conditions.

Acknowledgements

This research is a result of the T2017-05-33 project. We would like to thank the staff and

Table 3. Air temperature, air humidity and light gathered by the first sensor node

No.	The first sensor node			Standard meter			Error		
	T (^oC)	Rh (%)	E (lux)	T (^oC)	Rh (%)	E (lux)	ΔT (^oC)	ΔRh (%)	ΔE (lux)
1	29	68	30	31.2	72.4	31	2.2	4.4	1
2	29	64	24	30.9	68.4	23	1.9	4.4	- 1
3	29	62	17	30.6	65.7	16.3	1.6	3.7	- 0.7
4	29	60	16	30.5	63.1	15.8	1.5	3.1	- 0.2
5	29	60	20	30.4	62.7	19	1.4	2.7	- 1
6	29	60	11	30.4	61.5	11.8	1.4	1.5	0.8
7	29	57	10	30.2	58.7	10.1	1.2	1.7	0.1
8	29	55	8	30.1	57.7	8.1	1.1	2.7	0.1
9	29	54	12	30.1	55.9	11.8	1.1	1.9	- 0.2
10	29	50	25	29.8	54.6	24.8	0.8	4.6	- 0.2
11	28	49	22	29.8	54.1	20.9	1.8	5.1	- 1.1
12	28	48	27	29.7	52.2	25.5	1.7	4.2	- 1.5
13	29	47	31	29.6	51.7	30	0.6	4.7	- 1
14	28	46	28	29.5	50.4	26.6	1.5	4.4	- 1.4
15	28	45	24	29.6	50.1	22.7	1.6	5.1	- 1.3
16	28	45	21	29.6	49.5	21.4	1.6	4.5	0.4
17	28	44	22	29.5	48.8	22.4	1.5	4.8	0.4
18	28	44	22	29.2	49.2	22.1	1.2	5.2	0.1
19	29	43	24	29.3	48.5	24.8	0.3	5.5	0.8
20	28	42	31	29.2	47.4	30.8	1.2	5.4	- 0.2

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