CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216

DOI: 10.3303/CET1871028

Design of Real-time Monitoring System for CO_2, CH_4 and Various Environmental Factors in Intelligent Greenhouse

Fang Cheng*, Hua Jin, Hongyan Shen

College of Information Science and Technology, Agricultural University of Hebei, Baoding 071000, China
94132524@qq.com

In view of the poor real-time performance and the lack of diverse monitoring means of the greenhouse monitoring system, a cloud-based smart greenhouse monitoring system is designed using wireless sensor networks technology and the cloud technology. The system takes the cloud server as the core, and users can access the cloud server remotely through the PC terminal or mobile phone online, so as to realize the real-time monitoring and control of the greenhouse environmental factors(temperature, moisture, illumination). In addition, in order to avoid atmospheric pollution caused by excessive greenhouse gas emissions, the system adds on-line monitoring of the main greenhouse gases (CO_2, CH_4) in the greenhouse. With this system, we can achieve the goal of increasing crop yield and reducing environmental pollution. The experimental results show that the system has high stability and accuracy, and is easy to operate. It is suitable for popularization and application in greenhouses.

1. Introduction

North China has distinct four seasons with dry and cold winter and hot and rainy summer, thus impeding the growth of crops, especially vegetables. Therefore, the greenhouse becomes necessary for growing vegetables. However, the traditional greenhouse applies manual or wired data acquisition mode. The manual mode is hard to ensure the accurate and real-time data, and the wired mode needs multiple wires which is difficult to arrange and waste manpower and material resources.

In recent years, as the development of Wireless Sensor Networks (WSN), it is broadly applied in precision agriculture and modern agriculture (Huang et al., 2016; Halber and Chakravarty, 2018; Wand and Zhang, 2016; Saha and Biswas, 2017; Sorrente et al., 2017; Zheng et al., 2016). Many researchers designed various smart greenhouses monitoring systems with WSN according to their requirements (Song et al., 2016; Peng and Zeng, 2017). These systems could monitor and adjust temperature, humidity, illumination and other environmental factors in the greenhouses automatically. A smart greenhouse monitoring system based on WSN was designed, which made it possible for environmental control through multiple collection nodes (Hua et al., 2013). The 6LoWPAN WSN monitoring system was constructed by combining IPV6 with WSN to enable the real-time monitoring and alerting for the greenhouse (Gan et al., 2014). The monitoring system with WSN and TinyOS was built. The multi-sensor data fusion was used to collect data, which ensured the high speed and good stability of the sensor (Wang et al., 2014). The agricultural greenhouses communication protocol (AGCP) was proposed, and it was a new protocol that solved the problem of disunited Internet of Things (IoT) communication protocol. The protocol was used to set up the monitoring system based on IoT, thus offering the efficient monitoring of the environmental information (Liao, 2016).

The above systems avoid using wired devices which need complicated wire arrangement for remote data transmission. This greatly improves the economic efficiency and flexibility of data transmission. However, most of the platforms fail to achieve real-time remote monitoring and control. Relying on a single computer, the processing performance is dragged down by slow speed, long delay, and the lack of diverse monitoring means. Hence, this research designed a smart greenhouse monitoring system that enabled the cloud monitoring by integrating the ZigBee WSN and the Cloud technology. The system sends the collected data to the cloud server one layer after another, so the user can monitor and manage the greenhouse environment remotely at the mobile phone or PC terminal. In addition, in view of the current situation of excessive

Please cite this article as: Cheng F., Jin H., Shen H., 2018, Design of real-time monitoring system for co2, ch4 and various environmental factors in intelligent greenhouse, Chemical Engineering Transactions, 71, 163-168 DOI:10.3303/CET1871028

greenhouse gas emissions in agriculture (Jeong et al., 2018), the system designs a real-time monitoring system for the main greenhouse gases(CO_2, CH_4) by using wireless sensing technology, which can provide data support for reducing greenhouse gas emissions in the greenhouse. On this basis, through the rational arrangement of fertilization and irrigation, the goal of intelligent agriculture and low carbon agriculture can be truly realized.

2. The overall design of the system

The system has a layered design, consisting of three layers with different functions. From the bottom to the top, there are sensor-controlling layer, decision-making layer and web application layer. The bottom layer provides data service for the top layer and the top gives instructions to the bottom. The overall structure of the system is shown in Figure 1.

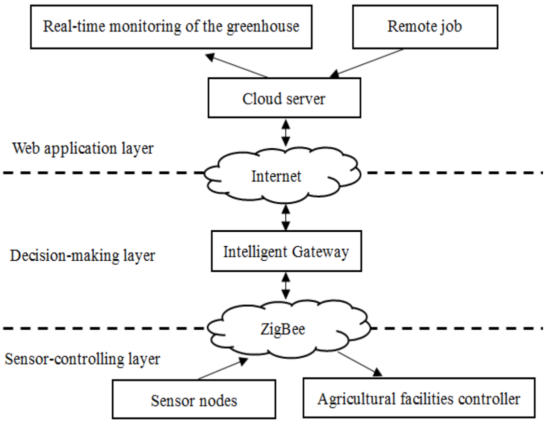


Figure 1: Structure picture of the system

The sensor-controlling layer is at the bottom, and mainly has two functions. On one hand, it connects temperature, humidity, light, CO_2 and CH_4 sensors and other sensors so as to collect data and transmit it to decision-making layer through ZigBee network. On the other hand, it gains instructions like ventilating adjustment instruction, light adjustment instruction, irrigation instruction from the decision-making layer and implements them.

Decision-making layer is at the middle. Its first function is transmission. It passes on the data from the sensor-controlling layer to the web application layer, and passes down the instructions given by web application layer to the sensor-controlling layer for implementing. The second function is that it gives instructions to the sensor-controlling layer automatically and sends messages to web application layer by referring to the sensor data and parameters like date when the default condition is met in case that the user would check. For instance, at 7:30 am, it gives the instruction of raising the roller shutter to increase the indoor light intensity when the outdoor light intensity reaches a specific number.

The web application layer is at the cloud, the top layer. It stores and summarizes data which finally is displayed on webpage for users to browse it at any time and in any place.

3. Hardware design

3.1 The design of sensor-controlling layer

The sensor-controlling layer communicates with the decision-making layer through ZigBee network. ZigBee with the advantage of low power consumption, low cost, high efficiency and high capacity, is mainly used in short-range wireless communications (Mao et al., 2015; Zhang and Liu, 2018). Thus, it is suitable for transmitting monitoring data and instructions and the best choice for greenhouses to construct wireless communication network.

ZigBee is a wireless network protocol for low-speed and short-range transmission. The protocol composes of physical layer (PHY), media access control layer (MAC), transport layer (TL), network layer (NWK) and application layer (APL) from the bottom to the top. PHY and MAC follow the IEEE 802.15.4 standard while ZigBee Alliance standardizes the network layer protocol and application framework. The ZigBee protocol stack is shown in Figure 2.

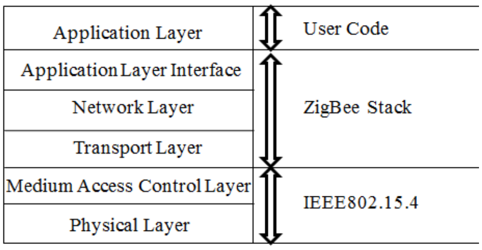


Figure 2: ZigBee protocol stack

3.1.1 DHT22 temperature and humidity sensor nodes

The temperature and humidity sensor node used in the greenhouse requires small size, low power consumption and high precision, hence, the DHT22, a composite temperature and humidity sensor node with digit signal input, produced by Guangzhou Mr Loose Electronics CO., Ltd was employed. It composes of a capacitive humidity sensing component and a NTC temperature measuring component and connects with a high-performance 8-bit microcontroller, thus, it has high precision, high reliability and long-term stability.

When power is supplied to DHT22, don't send any instruction to the sensor within one second to pass the unstable status. The single-wire communication is used between the sensor and Arduino and each communication is about 5 milliseconds. Arduino issues a query signal, then DHT22 issues a response signal outputting 40-bit data with the format of 16-bit humidity data+16-bit temperature data+8-bit checksum. When the temperature is below 0 ℃, the top digit of temperature data is 1, otherwise it is 0. The checksum is the last 8 bits of the sum of high humidity (8 bits) + low humidity (8 bits) +high temperature (8 bits) + low temperature (8 bits). Its sequence diagram is presented in Figure 3. The Design of DHT22 Temperature and Humidity Sensor Nodes is shown displayed in Figure 4.

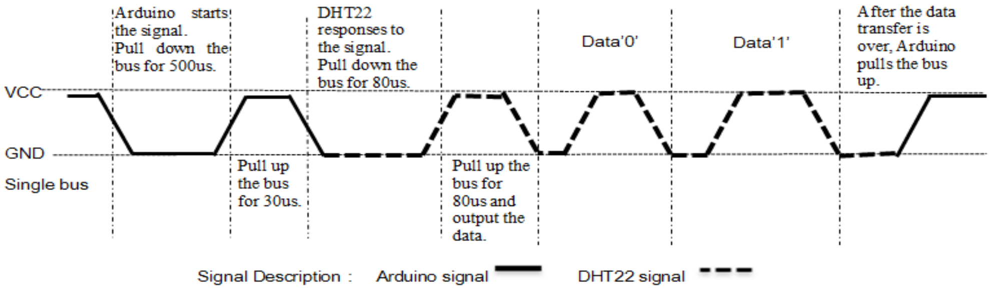


Figure 3: The DHT22 sequence diagram

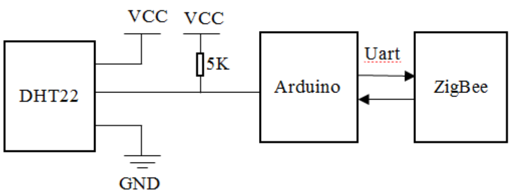


Figure 4: The design of DHT22 temperature and humidity sensor nodes

3.1.2 The BH1750FVI light senor node

The light sensor of small size, low power consumption and high precision is also needed in greenhouse, so the digital light sensor BH1750FVI produced by RHOM was applied.

Featuring low power and small error, it is connected with microcontroller using I2C digital interface, outputting illumination range of 1~65535lux.

BH1750FVI supports single or continuously two measurement mode and each mode provides three resolutions-0.5lux、1lux、4lux to choose from. The measurement with higher resolution takes longer time. In single measurement mode, the sensor will enter “Power Down” mode automatically after the measurement. The design of light sensor node is shown in Figure 5.

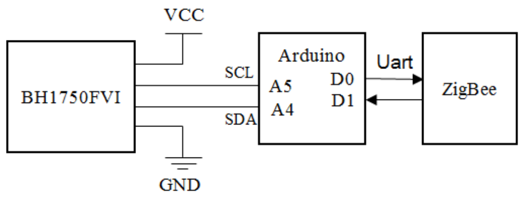


Figure 5: The design of light sensor node

3.1.3 CO_2 sensor node

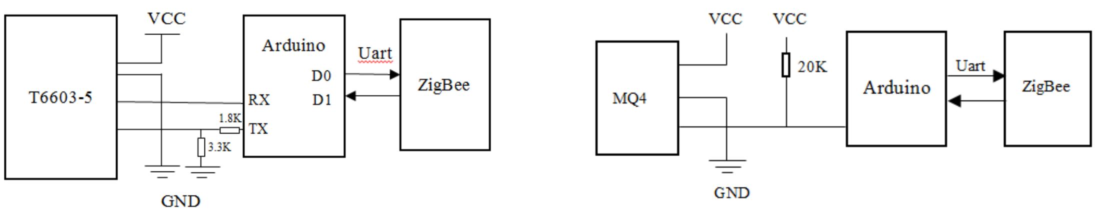
The CO_2 sensor node is T6603-5 made in American GE Company. It can be driven in two ways- serial UART query from 1, 2 pin and pulse width measurement 5 pin. The sensor with 400~2000ppm measurement range and 5V working voltage has table performance.

When using the serial UART query to input, it should be noted that the power supply voltage (5V) differs from the output voltage of the serial interface (3V). Therefore, two resistances should be used to convert the electrical level and to prevent the overvoltage of the chip.

The baud rate of T6603-5 serial port is 19200. The microcontroller sends query instruction FF FE 02 02 03 to T6603-5 and receives the reply of FF FA 02 XX YY. The last 2 digits of the reply shows the CO_2 concentration, and the calculation method is XX*255+YY. Figure 6a shows the design of CO_2 sensor node.

3.1.4 CH_4 sensor node

MQ4 methane sensor based on gas sensor is used. The sensor is composed of miniature AL2O3 ceramic tube, SnO2 sensitive layer, measuring electrode and heater. The heater provides the necessary working conditions for gas sensors. The sensor's working voltage is 5V, so it is easy to access the system. At the same time, it outputs voltage values through analog signals, so the measurement is very simple and convenient. The design of CH_4 sensor node is shown in Figure 6b.



(a) The design of CO_2 sensor node.

(b) The design of CH_4 sensor node.

Figure 6: CO_2 and CH_4 sensor nodes

3.2 The design of decision-making layer

The decision-making layer takes ATmega32u4 and Ar9931 as control core. ATmega32u4 chip not only has both digital I/O port and analog I/O port, but also support the communication of serial port SPI, I2C, UART. Thus, the chip makes it easy to connect variable sensors to monitor the environment and control relays, lights, motors and other devices. It is also connected to the ZigBee network module via D0, D1 digital port, thus communicating with the sensor controlling layer. Ar9931 chip with the function of network communication and Wi-Fi enables the communication between decision-making layer and web application layer. ATmega32u4 and Ar9931 send messages mutually through virtual serial port bridge. Figure 7 presents the design of decision-making layer.

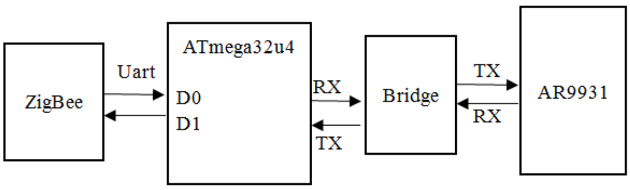


Figure 7: The design of decision-making layer

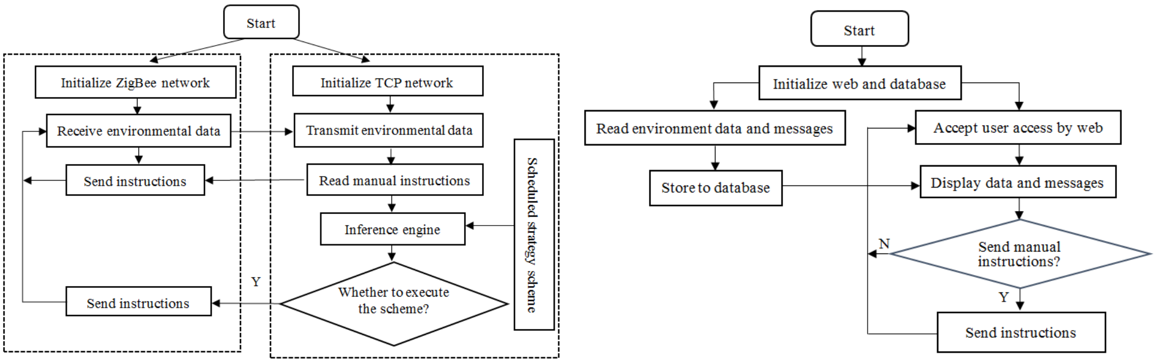
4. Software design

4.1 The software design of decision-making layer

The decision-making layer mainly consists of two modules: ATmega32u4 and Ar9931. The ATmega32u4 module uses Arduino to develop a program while the Ar9931 module applies OpenWrt to finish programming with Python language. When the module is powered up, ATmega32u4 will firstly initialize the ZigBee network. On one hand, the network receives environmental data of sensor-controlling layer which will be sent to Ar9931 from the serial port, on the other hand, it enables Ar9931 to give instructions to the designated sensor controller. Having gained the environmental data, Ar9931 will not only transmit the data to the web application layer via TCP network, but also constantly monitor it. If the condition set in advance is satisfied, Ar9931 will make decisions and send the controlling instructions from the serial port to sensor controller. The specific software workflow is shown in Figure 8a.

4.2 The software design of web application layer

The wed application layer regards the cloud server as the core, and its program is developed with PHP language. The cloud server receives and stores environmental data and gives the user’s instructions. Thanks to the separate network address of the cloud server, the user only needs to input the network address to access the server, thus monitoring the data in the greenhouse. The HTTP protocol, a traditional way to transmit data, can only meet the one-way data sending from the lower layer to the upper layer. To make it possible for giving instructions from the upper layer to the lower layer, the system used TCP long connection method to achieve the bidirectional communication. It means that Ar9931 chip of decision-making layer asks the web application layer to build TCP connection in the initializing period, hence constructing the bidirectional data communication channel. The software workflow in detail is displayed in Figure 8b.

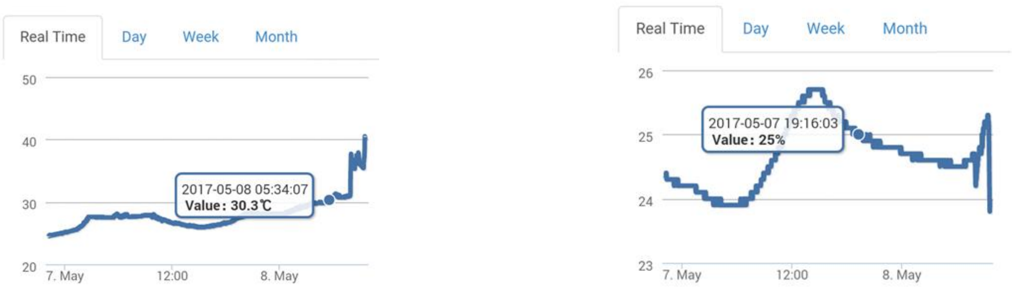


(a) Software workflow of decision-making layer.   *(b) Software workflow of decision-making layer.*

Figure 8: The software design

5. System test

A greenhouse in an experimental base was chosen to test the system stability and operability. According to the area of the greenhouse, ten sensor nodes were equipped in different places. Those nodes were set to upload data once a minute. Figure 9 shows the curves of temperature and humidity in a certain period time.



(a) Temperature.   *(b) Humidity.*

Figure 9: The curves of Temperature and humidity.

The experimental result demonstrated that the data sent by sensors had been received and stored by the web application layer accurately and completely. The remote-control function responded quickly and implementing institutes carried out the instructions well. In addition, the environmental data were shown in graph, making it more intuitive. Therefore, the system is operable, stable and reliable in both software and hardware design, showing its promotional value.

6. Conclusions

Based on ZigBee WSN and cloud technology, this study builds a real-time monitoring system for greenhouse. On the one hand, the system upgrades the existing monitoring system. With cloud server, the user can remotely monitor the environment in the greenhouse via mobile phone or PC terminal. As the cloud and communication technology becomes mature, the system is better promoted and applied in the greenhouse. On the other hand, the system enables greenhouse data sharing by transferring the environmental data from different greenhouses to the cloud server, thus providing data support for strategy optimization.

Acknowledgments

This work is supported by Plan Project of Research and Development of Science and Technology of Baoding, China. (Grant No.17ZN001, 14ZS005).

References

Gan K.F., Wang J., Zhang D.M., 2014, Design of Greenhouse Monitoring System for 6LoWPAN Wireless Sensor Network, Jiangsu Agriculture Sciences, 42(9), 371-374.

Halber A., Chakravarty D., 2018, Wireless relay placement optimization in underground room and pillar mines, Mathematical Modelling of Engineering Problems, 5(2), 67-75, DOI: 10.18280/mmep.050203

Hua J., He H. J., Yin H., 2013, Agricultural Greenhouse Environment Monitoring and Control System Based on WSN, Journal of Agricultural Mechanization Research, (11), 135-139.

Huang Z.H., Zhang B., Lan Y.B., Zhou Z.Y., Wu L.L., 2016, Farm Field Data Collection Based on UAV-WSN, Journal of South China Agricultural University, 37(1), 104-109.

Jeong S. T., Kim G. W., Hwang H. Y., Kim P. J., Kim S. Y., 2018, Beneficial effect of compost utilization on reducing greenhouse gas emissions in a rice cultivation system through the overall management chain, Science of the Total Environment, 613-614, 115-122, DOI: 10.1016/j.scitotenv.2017.09.001

Liao J.S., 2016, Design of Agricultural Greenhouse Environment Monitoring System Based on Internet of Things, Transactions of the Chinese Society of Agricultural Engineering, 32(11), 233-243, DOI: 10.11975/j.issn.1002-6819.2016.11.033

Mao P.J., Jiang S., Wang J., Zhang F., Qiu Z. M., 2015, Design of Wireless Monitoring System for Greenhouse Environment Based on ZigBee, Journal of Chinese Agricultural Mechanization, 36(1), 102-106.

Peng H., Zeng B., 2017, Intelligent Greenhouse Environment Control Based on Fuzzy Neural Network, Journal of Agricultural Mechanization Research, 39(6), 43-49.

Saha S., Biswas K., 2017, A comparative study of Fiber Bragg Grating based tilt sensors, Review of Computer Engineering Studies, 4(1), 41-46, DOI: 10.18280/rces.040108

Song Y.X., Wang J.Z., Zhang X.J., 2016, Greenhouse Environment Parameters Optimization and Wireless Monitoring Based on Maximize Profit Margin, Sensor Letters, 14(11), 1129-1137, DOI: 10.1166/sl.2016.3757

Sorrente B., Michau V., Fleury B., Conan J.M., Sauvage J.F., 2017, Measurement of the index field with a pyramidal sensor, Instrumentation Mesure Metrologie, 16(1-4), 213-228, DOI: 10.3166/I2M.16.1-4.213-228

Wang X.W., Zhang W., 2016, Research on Crop Diseases and Insect Pests Forecasting System Based on Wireless Sensor Network, Northern Horticulture, (9), 204-207.

Wang Y.P., Zhang B.H., Dong L.R., 2014, Design of Intelligent Greenhouse Monitoring System Based on WSN and TinyOS Technology, Jiangsu Agriculture Sciences, 42(8), 408-410, 418.

Zhang H., Liu F., 2018, Spatial and temporal disparities in agricultural carbon emissions in xinjiang and decomposition of impact factors, Chemical Engineering Transactions, 66, 553-558, DOI: 10.3303/CET1866093

Zheng Y.H., Kong Q.Z., Yang N., Huang Y., 2016, WSN System Based on Multi Parameter Fusion of Physical and Spatial Parameters for Water Saving Irrigation Management, Water Saving Irrigation, (3), 65-67, 71.