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Asian Agricultural Research 2017, 9(2): 39 -43, 71

Application Study of Greenhouse Environment Monitoring System Based on ZigBee Technology

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Abstract Against the demand of intelligent greenhouse construction of facility agriculture, greenhouse environment monitoring system is developed. The system contains three-layer architecture: sensor network layer at the bottom, data transmission convergence layer in the middle and monitoring application layer on the top, which is different from design idea of the existing system architecture. The bottom layer uses ZigBee wireless communication technology to construct wireless sensor network, and node type contains coordinator, router and acquisition terminal. Acquisition terminal is distributed in each greenhouse to collect data and play the role of wireless transmission, and router plays the function of data forwarding as the bridge of acquisition terminal and coordinator. Middle layer is composed of monitoring software developed by LabVIEW software of NI Company and coordinator, which is used to gather data from the bottom layer. The top layer is comprehensive monitoring platform developed by Java language, which is used to gather greenhouse data of all plantation bases in one region, thereby providing comprehensive information service for government, enterprise and farmer. Greenhouse environment monitoring system realizes data collection and sharing of greenhouse environment information (air temperature, air humidity, light intensity and carbon dioxide concentration). Via test verification, the system's operation is stable, with certain application value.

Key words Facility agriculture, Intelligence, System architecture, Wireless sensor network

1 Introduction

According to the 13 *th Five-year Planning Outline*, it is clear to list "accelerating the pace of agricultural modernization" as important development task, and central No. 1 document of 2016 also issued impelling the realization of agricultural modernization. It could be predicted that future China's facility agriculture will take the scale and intensive development way, and automation, information and intelligence of facility agriculture are also realized inevitably[1-2]. For scale planting enterprises, it corresponds with development demand of future facility agriculture to use new generation of information technology to monitor and regulate internal environment parameters of greenhouse, and improve production and management efficiency of planting enterprises and decline artificial input by technical means, thereby realizing scale operation model. However, the existing market products are based on mobile communication network GPRS technology, with high hardware cost and operation fee, which is difficult to be implemented. In researches on greenhouse monitoring system based on ZigBee technology, most scientific research achievements are still at theoretic research stage, especially the solution case for rear wall sunlight greenhouse of the North could not match with demand. For above problems, a set of greenhouse environment monitoring system corresponding with practical demand and suitable for scale production is proposed in this paper, thereby truly realizing environmental measurement and production control.

Received: November 24, 2016 Accepted: January 26, 2017

Supported by Applied Technology Research and Development Fund Plan Item in Inner Mongolia (20140114).

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2 Introduction of system architecture

The system architecture contains three layers. Sensor network layer is at the bottom and is composed of wireless data acquisition terminal and router set in greenhouse, which is used to collect and transport various environmental parameters in greenhouse. Data transmission convergence layer is in the middle and is constituted of software and hardware system of enterprise monitoring center, namely monitoring software and coordinator, which is used to collect data transported from bottom layer and transport data to comprehensive information service platform. Monitoring application layer is on the top, and is composed of computer client and mobile client, which is used for remote production management of plantation production base. Compared with the existing market cases, the solution scheme adds data transmission convergence layer between top and bottom layers of the system architecture, which could guarantee real-time and stable data transmission, and solve the problems of crowded data communication and bad real time. System architecture is shown as Fig. 1.

Wireless sensor network (WSN) is composed of various nodes disposed in data monitoring region. All nodes form a multi hop ad hoc network in the form of wireless communication to perceive, collect and treat the information of perceptual objects in network cover region. ZigBee is a kind of two-way wireless communication technology with close distance, low power consumption and low cost, and contains three kinds of nodes: coordinator node, router node and terminal acquisition node, which constitutes bottom sensor network with ad hoc network function. Coordinator is installed in enterprise's monitoring center, which is in charge of establishing network and deploying network member's address, and completes the gather of greenhouse base data. Router node is installed in each greenhouse penthouse to realize data forwarding of acquisition terminal in the greenhouse and data forwarding function of last greenhouse router node. Terminal node is installed in greenhouse to realize specific function. If greenhouse needs installing many acquisition nodes, data transmission follows the manner from far to near, which transports data to the greenhouse router node step by step[3-6]. Data of each greenhouse are transmitted from far to near by router in penthouse, finally completing data convergence in coordinator of enterprise monitoring center.

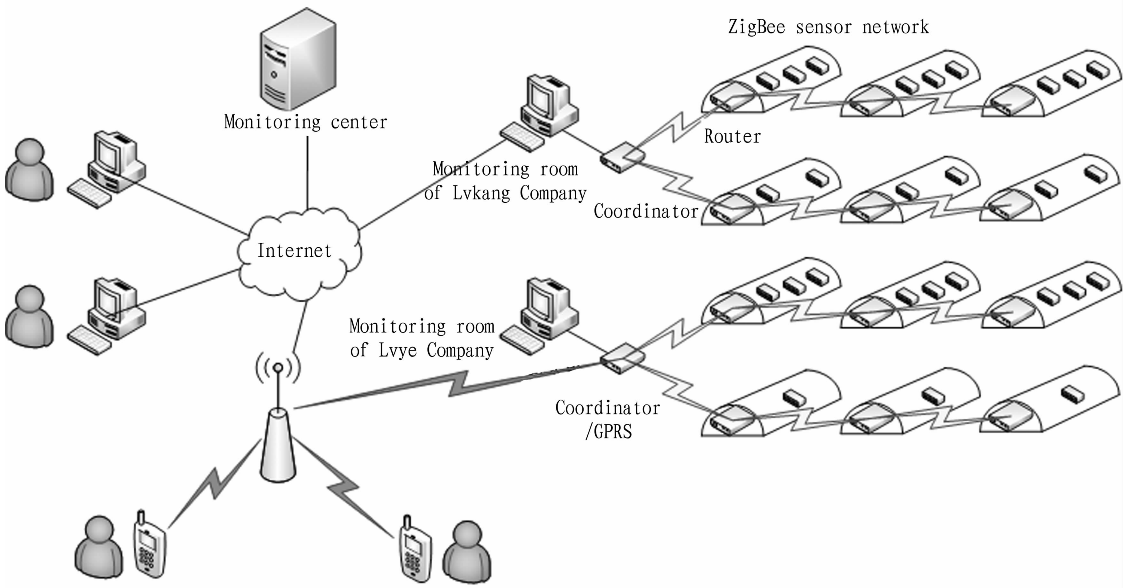

Fig. 1 System architecture chart

3 System hardware

The system uses data acquisition terminal to realize real-time collection of greenhouse environment parameters (air temperature, air humidity, light intensity and carbon dioxide concentration). Terminal cost is only 600 yuan, while market cost of the product realizing the same function based on GPRS technology is about 1500 yuan. The obtained research achievements use wired design scheme in hardware part, and the selected sensor should be connected with hardware core circuit by open wire, which causes inconvenient field installation, difficult debugging and high failure rate. In the system, the hardware part uses complete wireless design idea, and three kinds of sensors and power module (lithium battery) are integrated together, which could complete independently collection, display and transmission of greenhouse environment parameters, low-voltage alarm and charging. ZigBee wireless communication module is the core of hardware system, and its advantages are as below: it belongs to free frequency band and open; it does not need contributing any communication fee except hardware cost; it realizes the demand of low power consumption and long transmission distance in the function[7-11].

3.1 Hardware design of data acquisition terminal Data acquisition terminal is composed of power module, ZigBee module, sensor module and LCD liquid crystal display module. Upholding the complete wireless design idea, terminal integrates three kinds of sensors and power module circuit together, which is simple, portable and practical. Taking 5-min collection period as the example, lithium battery could sustainably supply power for more than half a year. Hardware structure of data acquisition terminal is shown as Fig. 2.

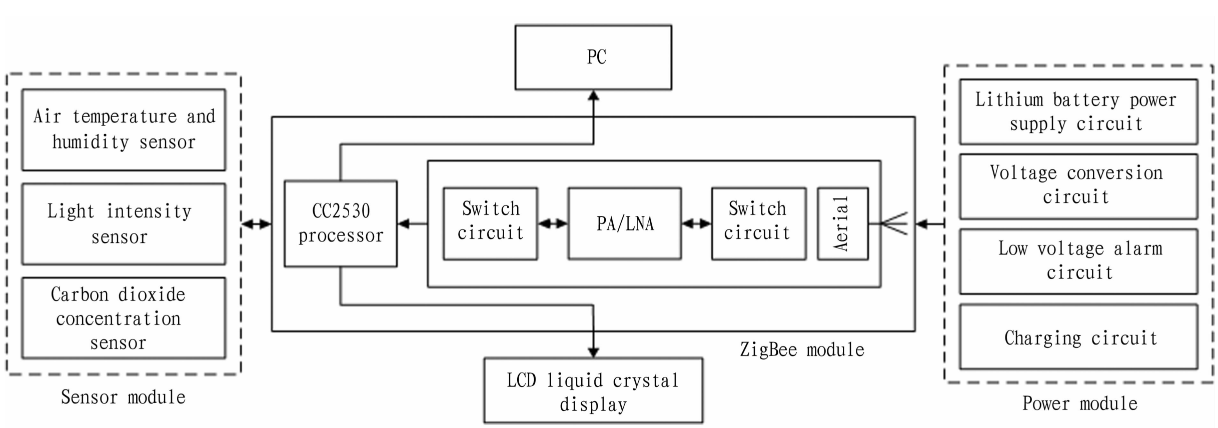

Fig. 2 Hardware structure of data acquisition terminal

3.2 Sensor module Acquisition terminal integrates air temperature and humidity sensor, light intensity sensor and carbon dioxide concentration sensor together to collect greenhouse environment parameters, and specific parameters of sensor are shown as Table 1. Sensors select in-line package and are integrated in data acquisition terminal, which is convenient for debugging, installment and maintenance of the device. ZigBee processor is often in dormant state, and is automatically woken according to the fixed time period, and then issues a collection instruction to each sensor. Sensor implements the function of data acquisition and sends data back to ZigBee processor for corresponding treatment.

Table 1 Technical parameters of three kinds of sensors

Sensor type	Technical parameters	Measurement time//ms	Power consumption mA	Price yuan
Air temperature and humidity sensor(DHT22)	Temperature measurement range: −40 – 80 ℃, accuracy: ±0.2 ℃(repeatability) Humidity measurement range:0 – 100%, accuracy: ±2% RH(repeatability)	2000	20	17
Light intensity sensor(BH1750)	Measurement wavelength range:400 – 700 nm, peak wavelength:560 nm Measurement range:0 – 65535 lx, accuracy: ±2%	1000	10	10
Carbon dioxide concentration sensor(S8 0013)	Measurement range:0 – 2000 μL/L, which could be expanded to 10000 μL/L Measurement accuracy: ± 3% of reading	2000	25	420

Theoretic temperature of greenhouse should be between 12 and 35 ℃, while theoretic air humidity should be between 50% and 90%, and the selected air temperature and humidity sensor corresponds with application demand. Under direct sunlight of summer, light intensity could reach between 60000 and 100000 lx. Via test verification, the maximum light intensity of greenhouse is between 30000 and 40000 lx, so the selected light intensity sensor also corresponds with application demand. Carbon dioxide concentration of greenhouse is generally within 1300 ppm, which belongs to measurement range of sensor, and the selected sensor also corresponds with application demand.

3.3 Power circuit module Terminal uses complete wireless design concept, and selects lithium battery with output voltage of 3 V and capacity of 3000 mAh as input power. Via the chip TPS60210, voltage conversion is conducted to provide input voltage for other module circuit. Meanwhile, the chip makes that voltage of lithium battery stabilizes over 1.8 V. When lower than the threshold, LED pilot lamp is open, indicating low-voltage alarm, and lithium battery could be charged by using Mini-USB mouth. TPS60210 low-voltage alarm circuit is shown as Fig. 3. Power consumption of whole hardware circuit collecting, displaying and sending data is about 0.056 mAh. If collection period is 5 min, there are 288 times of collection in one day, with the power consumption of 16 mAh. If using lithium battery with the capacity of 3000 mAh for supplying power, it could sustainably supply power for 187.5 days, which meets power supply demand of acquisition terminal under greenhouse environment. When electrical voltage exhausts, lithium battery could be charged, and then acquisition terminal could continue to work normally.

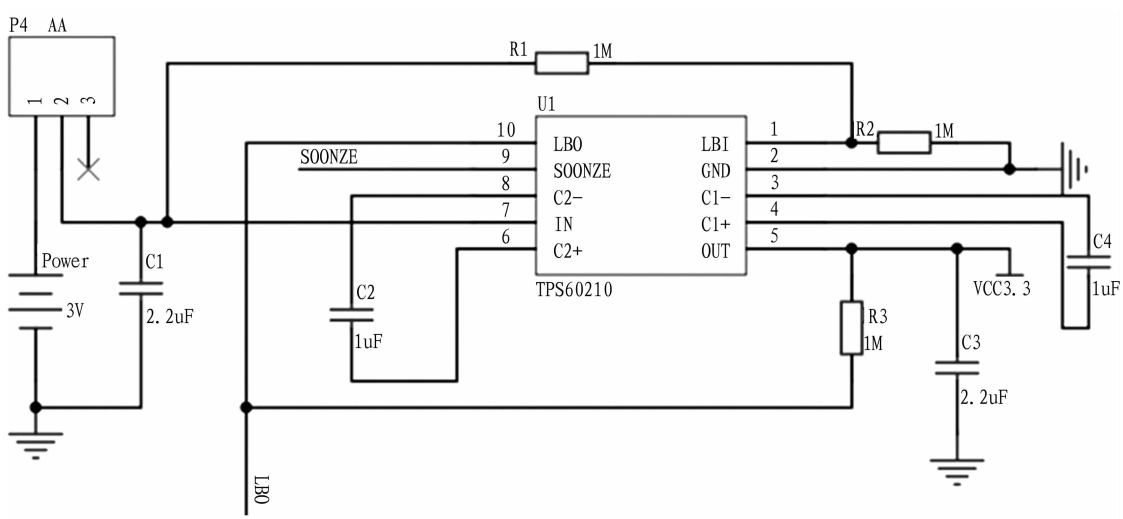

Fig. 3 Low-voltage alarm circuit

4 System software

The system uses IAR software development environment for program development of each terminal node in wireless sensor network. PC monitoring software design is conducted by using LabVIEW software platform of NI Company, and Java language is used to develop comprehensive information service platform of server.

4.1 Acquisition terminal program design Each acquisition terminal node of bottom sensor network is used to collect air temperature, humidity, light intensity and carbon dioxide concentration in greenhouse, and the collected data are displayed on local

LCD. Meanwhile, the data are transported to coordinator for processing by ZigBee wireless communication protocol. After terminal node has power, system initialization is firstly conducted, containing initialization of hardware peripheral and ZigBee protocol stack. After that, web search is conducted, and network is established by coordinator. After networking successfully, the collected data by sensor are sent to coordinator by ZigBee wireless communication protocol. After data transmission completes, processor of terminal node immediately enters a dormant state and waits auto waking up of next collection period[12-14]. Program flow of data acquisition terminal is shown as Fig. 4.

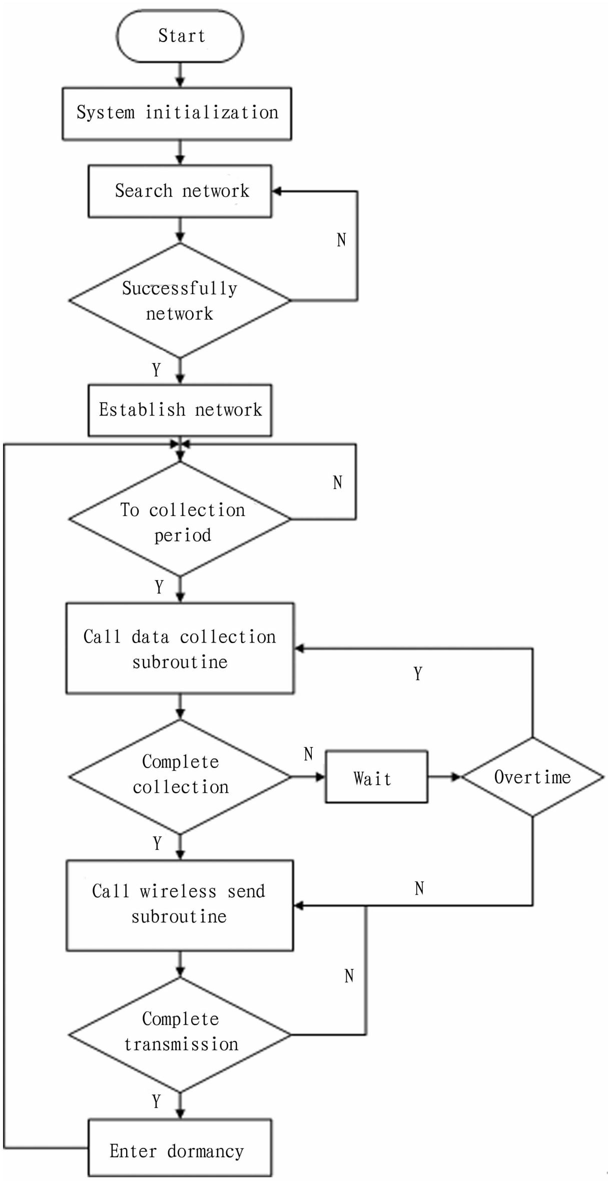

Fig. 4 Program flow of data acquisition terminal

4.2 PC monitoring software design The collected data are transported to coordinator for data aggregation by acquisition terminal. Coordinator connects with PC by serial ports, and the aggregated data are transported to PC by serial communication protocol, thereby playing display, judgment, alarming and feedback control functions by PC monitoring software. The data are conserved to local Access database, which is convenient for query and analysis processing of data in latter period. Meanwhile, local data are uploaded to server platform for data summary by TCP/IP protocol. Coordinator and the monitoring software constitute middle layer of system architecture, namely data transmission convergence layer, thereby guaranteeing real-time and stable data transmission. The interface of PC monitoring software is shown as Fig. 5.

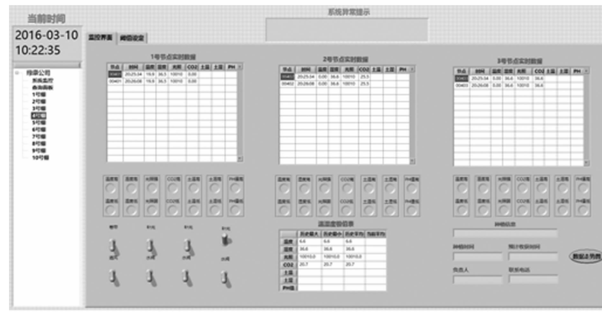

Fig. 5 The interface of PC software

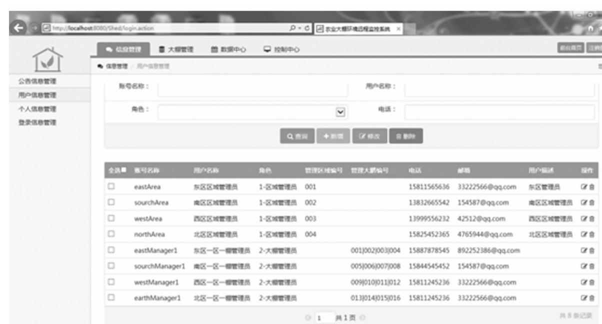

Fig. 6 Comprehensive information service platform

4.3 Development of comprehensive information service platform of server Greenhouse plantation of facility agriculture field greatly depends on plant growth environment data. In the times dominated by data, data are collected, conserved, deeply excavated, and then are responded to plantation field. It realizes intelligent control of greenhouse parameter debugging device, and truly meets scale development demand of plantation enterprise. The operation function of remote management breaks through the limitation of time and space on crop production management, and could greatly improve production management efficiency of enterprise and decline manual input. Comprehensive information service platform of facility agriculture of thing internet is established to build special database of greenhouse environment parameters for scale plantation enterprise, which aims to join in production management of enterprise and provide plantation scheme. Meanwhile, it could provide data support for government making decision at agricultural aspect and plantation knowledge and method for farmers. The platform could send real-time monitoring information, pre-warning information and agricultural knowledge for farmers by information terminal, thereby realizing intensive and network remote management of production site. The platform implements user rating login mode, and the users are divided into super user, area manager and greenhouse manager. Fig. 6 is login interface of super user of comprehensive information service platform.

5 The system's performance testing

To verify the stability of greenhouse monitoring system, three rear wall greenhouses from Bikeqi Project Demonstration Base of Hohhot City are selected for test experiment. Experiment period is one week, and data collection, transmission and treatment situation by software and hardware system in one week is analyzed. In the selected greenhouse, coordinator, router and data acquisition terminal are installed. The coordinator is installed in base monitoring center and connects with PC installing monitoring software. The three routers are installed in the selected greenhouse penthouse, and the three data acquisition terminals are installed in middle position of the selected greenhouse. Collection period of terminal node is set as 5 min. When implementing one acquisition command, the collected air temperature, humidity, light intensity and carbon dioxide concentration are transported to coordinator of base monitoring center via router, and then it enters into dormant state. After next collection period, data collection and sending function is implemented again. The maximum distance from terminal node to router node is 80 m, and router node is 150 m from coordinator of monitoring center. PC monitoring software displays and stores the received data information, and sends data to comprehensive information service platform of the server via internet. Via verification, monitoring software of the base could receive and process the gathered data, and stores data in comprehensive information service platform database of facility agriculture. But after observing background database, it is found that data disorder and loss phenomenon exists in data list. In the obtained 6048 groups of data collected by three acquisition terminals, there are 57 groups of error data, with error rate of 0.94%. Maybe it is caused by inherent packet and frame loss phenomenon of ZigBee wireless communication technology or unstable data transmission induced by self process difference of ZigBee module. However, data error in test period is within allowed range. Experiment proves that working performance of whole set of greenhouse monitoring system is stable, and reliability is higher, which is suitable for scale plantation enterprise, with higher application value. But it is future research focus to further increase data transmission stability of the system, improve system architecture and decline data error rate. The test data curve of 3 h in one day of experiment period is shown as Fig. 7.

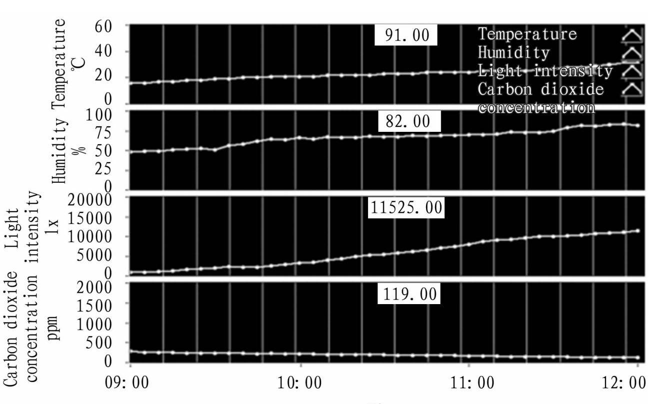

Fig. 7 Test data curve

6 Conclusions

In this paper, software and hardware design of greenhouse environment monitoring system of intensive facility agriculture is introduced. The developed intelligent acquisition terminal has four characteristics. Firstly, it completely realizes wireless connection, and installation is convenient, and it does not need wired connection; secondly, it has low cost and operation cost, and does not need paying monthly fee of network; thirdly, it is simple, and has low power consumption, low failure rate and high reliability. Fourthly, bottom sensor network realizes device interconnection, and data could be transmitted stably, with extremely low error rate. The system uses three-layer architectures, with high stability, strong safety, easy expansion and convenient maintenance and deployment. Greenhouse environment monitoring system based on ZigBee technology has the following advantages. (i) Terminal equipment takes the design idea of ultra low power consumption, and combines the sleep function of ZigBee module to use lithium battery with the capacity of 3000 mA · h. Taking 5 min collection period as the example, the battery could sustainably supply power for more than half a year. (ii) Terminal equipment uses ZigBee wireless communication technology. Compared with collection equipment using GPRS technology, the cost declines by more than 50%. It is suitable for intensive production mode, and could solve bottleneck problem of facility agriculture development. (iii) Bottom sensor network merges perception layer and transport layer in traditional architecture, which enhances interconnection among devices and makes data transmission of terminal node based on ZigBee have rationality. (iv) The system increases data transmission convergence layer between bottom sensor network and server platform, which enhances system stability, and solves the problems of data communication congestion and poor real-time.

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