Smart Greenhouse: A Real-time Mobile Intelligent Monitoring System Based on WSN

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***Abstract*—Wireless sensor network (WSN) is one of the most promising technologies in the 21st century. Applying WSN to life or production environment is becoming increasingly common. Incorporating the environment-sensing capability of wireless sensor networks into mobile monitoring systems can provide convenient control of the greenhouses anywhere, anytime. This paper designs and implements a real-time mobile intelligent monitoring system, which can collect data real time, transfer data automatically and provide remote control via mobile device. The system consists of acquisition and transmission system, control center and mobile control terminal. It comprises temperature, humidity, light sensors, sink node, server and mobile client. We deployed this system in the actual environment and demonstrate the effectiveness of the system.**

Keywords—wireless sensor networks, smart greenhouse, mobile monitoring

I. INTRODUCTION

Since time immemorial, agriculture production is greatly affected by climate and geographical location. People have been unable to change that until the emergence of greenhouse, which can adjust light intensity, keep temperature and humidity, meeting some corresponding requirements, and make it possible to grow crops anytime, anywhere[1]. But how to keep abreast of the greenhouse environment parameters and how to adjust these parameters according to the needs of different crops has become a major difficulty. With the development of computer technology and automatic control technique, a variety of monitoring systems have be applied to the greenhouse. However, most of the current monitoring systems are wired, with the drawbacks of wiring heavy-duty, large upfront investment, inconvenient post-maintenance, etc[2]. In the recent years, Wireless sensor networks (WSN), which integrates sensor technology, MEMS technology, wireless communication technology, embedded computing technology and distributed information management technology, has developed rapidly. Thus, it is expected that the WSN will be used commonly in applications in consumer electronics, home automation, home security, personal healthcare, industrial control and monitoring, asset and inventory tracking, intelligent agriculture, etc[3-5]. In the other hand, along with the popularity of smartphone, mobile communication control gradually become a trend. How to integrate the two technologies is the focus point of the design of our system.

In this paper, we design and implement a unified monitoring system which can monitor and control a large number of greenhouses by the control center and remote client terminals such as smartphone. We divided the greenhouses into different regions according to geographical location and deployed a sensor network to monitor environmental parameters in each region. All of the regions are managed by a unified monitoring center. Each region has an independent sink node, monitoring center gets the environmental parameters from these sink nodes, and then store them in the database. The monitoring system processes and analyzes these data then shows them to users in intuitive charts and curves. At the same time, the monitoring system can acquire the users' control commands via both control center and remote mobile devices to control the environmental parameters and provide alarm information. Our system accomplished intensive and networked modern management of greenhouse.

The remainder of the paper is organized as follows: In Section II we introduce the related work. In Section III we introduce the design and implementation of the monitoring system. In Section IV, we test our system and display the testing results. Finally we conclude our work and point out promising research direction.

II. RELATED WORK

At present, a lot of research about how to apply wireless sensor network technology to greenhouse has been done. Paper[6] analyzed the theory of monitoring system, introduced a design of sensor node hardware and software, and discussed the design of communication protocol of sensor nodes. Paper[7] pointed out that surrounding temperature and humidity of crop leaves is very important to the growth of crops, so it proposed a system which monitored the environment parameters surrounding temperature and humidity of crop leaves to prevent disease and promote the crop growth. An agricultural greenhouse [8] can be considered as a manmade solution to emulate a suitable ecosystem in order to grow crops rapidly. Also, the extensive farm or greenhouse requires the monitoring system or the control system to be built wirelessly. Wireless sensor network also will help improve existing systems installed the greenhouse ef?ciently and easily by radio [9].

III. DESIGN AND IMPLEMENTATION OF THE MONITORING SYSTEM

The greenhouse monitoring system which is based on WSN and mobile control technology mainly consists of sensor nodes, sink nodes, monitoring center and user client as shown in Fig. 1. According to the corresponding requirements, a large number of sensor nodes are deployed in a region, forming a

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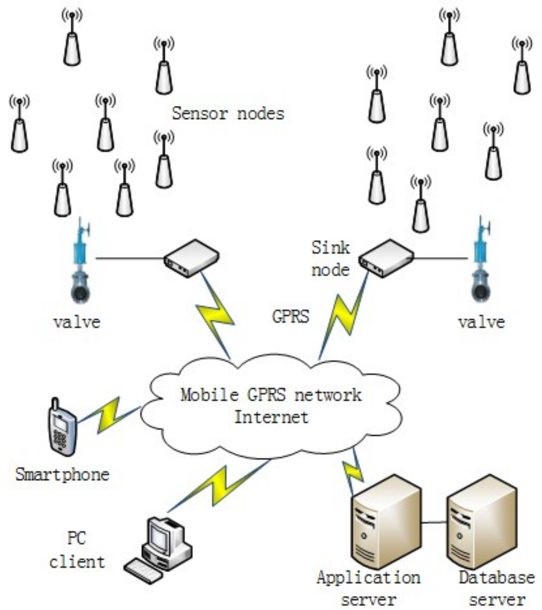

Fig.1 System Topology

self-organizing network to monitor and collect the temperature, humidity, light and other environmental parameters of this region. Then the collected data is sent to the sink nodes wirelessly. After sink nodes received the data, it transfer the data to the monitoring center through GPRS network. Sink nodes can also receive control commands sent by the monitoring center in turn. Monitoring center comprises application server, database server, and expert system and remote control terminals. The application server receives the data and stores them into the database while expert system analyzes the data, making appropriate control commands. And then these control commands are sent to the sink nodes. Sink nodes control the corresponding devices according the control commands. Users can get access to the data of environment parameters via remote mobile devices in real time. Also they can send their control commands to the sensor node through sink node to adjust the condition of greenhouse as expert system does.

A. Node Hardware

The hardware of the system includes sensor nodes and sink nodes. We designed and developed the sensor node hardware, as shown in Fig.2. The sensor node consists of a ZICM2410 programming module which is an IEEE 802.15.4 radio with a corporated antenna, a low powered ARM Cortex-M3 core with elaborated memory and an optional sensor suite. Our sensor node offers many unique features. Amongst the main features offered are Zigbee acquiescent RF transceiver, corporated antenna,ultra-low power consumption of 72Mhz STM32 with 512KB flash and information accumulation through RS232 serial port. Optional sensor suite includes incorporated temperature, light and humidity sensors. The sensor node supports the operating system C/OS which can be used to develop program expediently. It is powered by a 24V main. Sink node, as shown in Fig.3, is responsible for assembling the data which are collected by sensor nodes on the one hand, and communicating with a remote data center on the other. So

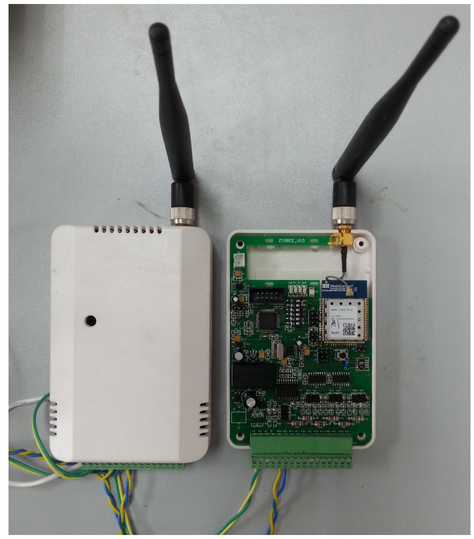
Fig.2 Sensor node hardware

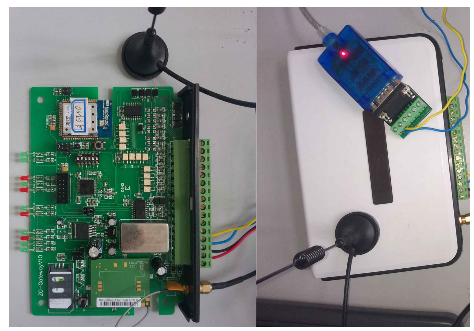
Fig.3 Sink node hardware

we integrate SIM900A into our sink node. SIM900A adopts industry standard interface and has the features of stable performance, appearance compact, cost-effective. It communicates with STM32 through the USART port. SIM900A has a built-in TCP / IP protocol stack which is easily to be used without re-developing. Data can be transferred to the Internet and be accepted through the GPRS network and Internet. In addition, in order to control the greenhouse environment parameters, sink node also includes a control circuit to control simple equipment through the relay.

B. The Communication Protocol

Wireless sensor network communication protocol provides reliable wireless communication between sensor nodes and sink nodes. In order to meet the demand of greenhouse monitoring, the system needs the communication protocol stack to provide the following functions: (1) Energy efficiency. Battery-powered sensor nodes are used in the system and their energy is limited, so we must extend the life cycle of the node as much as possible. (2) Data collection. Sink nodes need to collect the data of each sensor node in the network based on the system design requirements. (3) Parameter setting. Users must be able to adjust the sensor's acquisition cycle and set the parameters threshold according to their actual requirement.

The routing protocol we adopt is Collection Tree Protocol

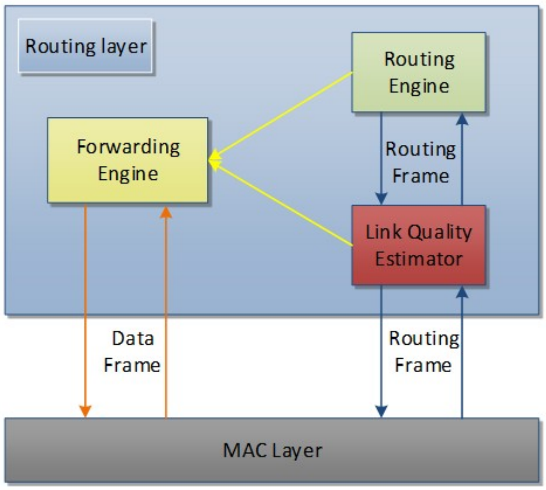

Fig.4 Communication Protocol Architecture

(CTP)[10] which has been implemented in the TinyOS. Its implementation consists of three parts: link quality estimator, routing engine and forwarding engine[11]. The architecture is shown in Fig.4. the link quality estimator estimates the single-hop ETX value (ETX, Expected Transmissions); routing engine decides which neighbor node can be the next hop base on the MAC and network layer information, such as congestion; forwarding engine maintains data packets queue and decides whether and when to send a packet. The current implementation of CTP meet the needs of the general situation, in order to apply to the greenhouse monitoring system, we carried out following two improvements:

1) Energy efficiency: The main energy consumption of the sensor nodes is for idle listening on the radio module. In order to reduce the energy consumption of this part, we adopt cyclic listening on the radio module. The RF module periodically sleeps and wakes. When the node wakes up, it starts to listen. In this period if there is some data needs to be received, the node will first receive data, and then go to sleep, otherwise, it will continue to sleep directly. The TinyOS operating system has already provided low power listening interface, however, CTP protocol does not use it. So we have added the low-power listening function into the implementation of CTP protocol, reducing the energy consumption of sensor nodes and prolonging the lifetime of the network.

2) Forwarding engine: In order for users to know the real-time network topology, we have improved the forwarding engine of CTP protocol. The previous forwarding engine is only responsible for sending original packets from the queue while after our improvement, the forwarding engine now can add the address of current node into data frame before sending it. When the monitoring center receives the data frame, it can parse out the transmission path of the data frame, and then get the network topology.

To allow users to adjust the period of sensor nodes collecting data, we adopt data dissemination protocol, which can reliably transmit small data items to every node in the network. The protocol is mainly used to implement the consistency of shared variables in the network. Every node in the network saves a copy of the shared variables. In our system, we set the period of collecting data as a shared variable. When users want to adjust the period, sink node first disseminates the new period, and after some time, every node in the network will receive the new period and then will collect data according to this new period. Fortunately, the dissemination protocol has been implemented in the TinyOS, so we can just use it in our system.

C. Node Software

Node software includes the embedded operating system kernel and application layer software. The operating system kernel[12] in our system is TinyOS, which is an open source, BSD-licensed, component-based operating system designed for low-power wireless devices, such as those used in sensor networks, ubiquitous computing, personal area networks, smart buildings, and smart meters. It provides hardware drivers, task and power management modules, and communication protocol stack. Node software architecture is shown in Fig. 5. All of the hardware resources are abstracted into appropriate components which can be used by other components. Task management module is responsible for scheduling the tasks created by the operating system and applications, and power management module manages the operation mode of the processor and the listening mode of RF transceiver, ensuring that the node wakes up at the right time, to minimize energy consumption and prolong the lifetime of the sensor network.

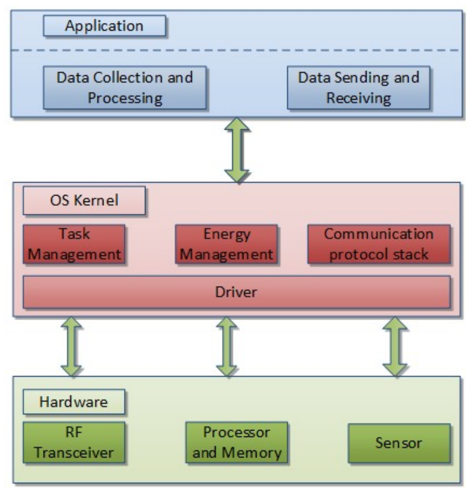

Fig.5 Node Software Architecture

Sensor node application works as shown in Procedure. 1. It establishes routing to the sink node first, and then collect sensor data and transfer data to the sink node periodically. The period of collecting data can be adjusted.

Sink node application works as shown in Procedure. 2. It manages the TCP/IP connection between monitoring center and GPRS module and receives data from sensor nodes, then transmits them to the monitoring center. At the same time, the sink node also can receive the control commands from monitoring center and then drive the corresponding valve to complete the control procedure.

Procedure 1 Application software of Sensor node workflow

```
1:  Power-up and Initializing
2:  Routing Setup
3:  Data Collection and Processing
4:  if Routing information exists then
5:      Transfer Data
6:      Set the timer
7:      Go back to: 4
8:  else
9:      Go back to: 2
10: end if
```

Procedure 2 Application software of Sink node workflow

```
Power-up and Initializing
Establish wireless network
loop
    Receive Data
    if Received Data is monitoring commands then
        Control devices according to the commands
    else
        if Connection is not established then
            Establish TCP connection
        end if
        Transfer Data to monitoring center
    end if
end loop
```

D. The Monitoring Center

Monitoring center is consist of application server, database server, and expert system. Application server communicates with sink nodes. Through test and operation, it indicates that establishing a connection between GPRS module and the monitoring center will take a long time and great costs. Therefore, when receive a connection request, we make the application server create a thread to manage related traffic. Once the connection is established, the application server maintains a persistent connection with the GPRS module by using the heartbeat packet. When the application server receives data, it parses out the environmental parameters and then stores them into the database server. User client can access the data by remote mobile devices. Expert system computes the current environmental parameters required according to the configuration parameters and certain algorithm, and then makes control decision after comparing with the actual environment parameters in the database. At last, application server sends control commands to the sink nodes.

E. Remote User Client

Remote user client includes computer client and mobile control client. We develop the computer client using WPF framework, C# and XAML language. Computer client accesses the monitoring center data via TCP/IP protocol and display them graphically to users. The computer client mainly provides functions as follow:

1) Data Display: mainly involve two parts, one is to display the average curve of each parameter of all the regions real time, and the second is to show the real-time data of each greenhouse.

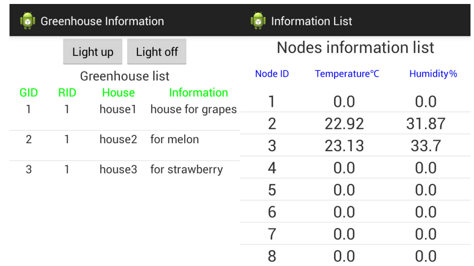

Fig. 6 User interface of mobile control client

2) System Configuration: when system initializes, the computer client sets the required control parameters, such as the best environmental parameters, alarm values of each parameter , and the frequency of data acquisition.

3) Alarm: When the collected environmental parameters exceed the setting alarm values, the computer client generates alarm messages.

4) History Data Query: the computer client provides history data query interface to display varying curve of parameters a period of time in the past.

5) Network topology diagram display: According to the path information acquired from the monitoring center, computer client can draw the network topology automatically. Users can know the current situation through the network topology.

F. Remote mobile control client

In recent years, with the rapid development of mobile Internet, smart phones and other mobile devices are widely used. In order for users to grasp the information of the greenhouse anytime and anywhere and can control the greenhouse environment parameters in time, we develop the mobile control client. The mobile control client is developed on the Android platform using java language. It provides a friendly user interface, making it convenient for users to get real-time environmental parameters and send control commands. With the addition of the mobile control client, the flexibility and timeliness of our system greatly increased. The user interface of the mobile control client is shown in Fig. 6.

IV. System Testing

We deployed the system actually. There are two monitored regions which are called regionA and regionB respectively. We deployed five sensor nodes and one sink node in each region. The data collection period of sensor node is set to 10 seconds. We tested this system a whole day, and calculated the average value by the hour of the collected data, the obtained data is shown in Fig. 7 - Fig. 9:

V. Conclusion

In this paper, we proposed a greenhouse environment mobile monitoring system that integrates temperature and humidity sensor, light sensor into a device to collect the information of greenhouse environment. Users can check and control the status of greenhouse environment in real time. Based on the characteristics of sensor node, such as low energy wastage,

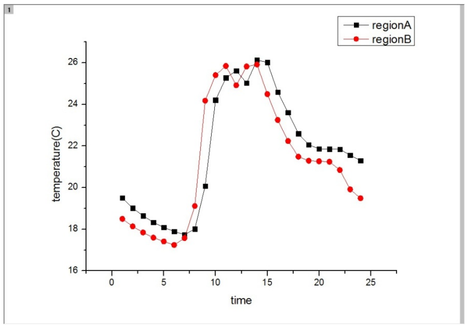

Fig. 7 temperature variation curve

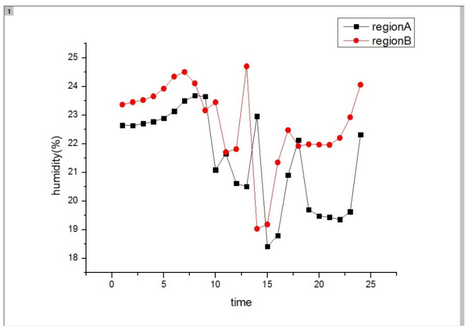

Fig. 8 relative humidity variation curve

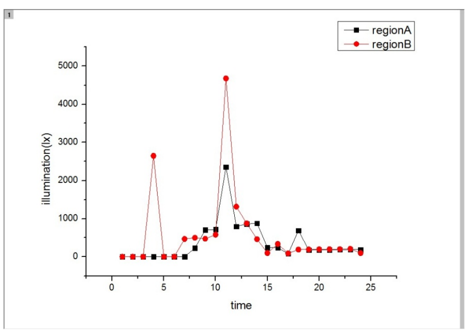

Fig. 9 light intensity variation curve

short communication range limited and self-organized, and combined with the requirements of actual application guide us the application architecture and services. Then we have introduced the selection and construction of hardware platform, protocol design, monitoring center, the mobile control client software in detail. After the actual deployment of our system on a testing environment, the test results indicate that our system is able to complete the design goals. Our system can be widely used in various Greenhouse and related fields, and has wide application foreground. In future work, we hope to deploy this system in the long-term, and accurately measure the performance of this system. Further research about reducing energy consumption, prolonging network lifetime and increasing the scope of the system will also be carried out.

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