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A wireless solution for greenhouse monitoring and control system based on ZigBee technology*

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Abstract: With the rapid development of wireless technologies, it is possible for Chinese greenhouses to be equipped with wireless sensor networks due to their low-cost, simplicity and mobility. In the current study, we compared the advantages of ZigBee with other two similar wireless networking protocols, Wi-Fi and Bluetooth, and proposed a wireless solution for greenhouse monitoring and control system based on ZigBee technology. As an explorative application of ZigBee technology in Chinese greenhouse, it may promote Chinese protected agriculture.

Key words: Greenhouse, Monitoring and control, Wireless, ZigBee, IEEE802.15.4, JN5121
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INTRODUCTION

Wireless technologies have been rapidly developed during recent years. Starting from military and industrial controls, it is now being widely applied in environmental monitoring and agriculture. Its advantages include the liability, simplicity, and low cost in both installation and maintenance. In greenhouse control applications, Serodio *et al*.(1998; 2001) developed and tested a similarly distributed data acquisition and control system for managing a set of greenhouses. Inside each greenhouse, a WLAN network with a radio frequency of 433.92 MHz was used to link a sensor network to a local controller. Morais *et al*.(1996) implemented a wireless data acquisition network to collect outdoor and indoor climate data of greenhouses in Portugal. Mizunuma *et al*.(2003) deployed a WLAN in a farm field and greenhouse to monitor plant growth and implemented remote control for the production system. Mancuso and Bustaffa (2006) worked at a short-term deployment of a wireless sensors network in a tomato greenhouse in the south of Italy.

In China, Liu and Ying (2003) reported a greenhouse monitoring and control system using the Bluetooth technology. The system collected environmental data from a sensor network in a greenhouse and transmitted them to a central control system. Qiao *et al*.(2005) introduced systematic frames of wireless sensor networks and expatiated their agricultural applications such as monitoring greenhouse, irrigation, precision farming and so on. Luo *et al*.(2006) designed wireless sensors for greenhouse monitoring. The wireless communication was based on nRF401 wireless module, working at 433 MHz ISM frequency. Wu *et al*.(2006) reported the design and implementation of Greenhouse Wireless Data Acquisition System based on CC2420, as a low-cost transceiver designed specifically for low-power, low-voltage RF applications at the 2.4 GHz unlicensed ISM band. Li *et al*.(2007) reviewed cable and wireless communications used in agriculture, and compared their advantages and disadvantages.

Wireless sensor technology, however, is still at

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its early development phase in China, and its applications in Chinese greenhouses remain few. In the current study, we compare the advantages of ZigBee with two similar wireless communications, Wi-Fi and Bluetooth, and propose a wireless solution for greenhouse monitoring and control system based on ZigBee technology.

COMPARISON OF ZIGBEE, WI-FI, AND BLUETOOTH PROTOCOLS

Wi-Fi, Bluetooth and ZigBee work at similar RF frequencies, and their applications sometimes overlap (Seager, 2006). In the current study, we chose the following five main factors of greenhouse networks to compare: cost, data rate, number of nodes, current consumption and battery life.

(1) Cost. ZigBee chip is US$ 1 or less, the lowest; Wi-Fi and Bluetooth chips are $ 4 and $ 3, respectively. The overall system cost can be significantly reduced by the employment of ZigBee chip.

(2) Data rate. ZigBee is 250 kbps, while Wi-Fi and Bluetooth are 54 Mbps and 1~2 Mbps, respectively. Despite the lowest data rate, ZigBee is sufficient for a greenhouse. Generally, data traffic in a greenhouse is low—usually small messages such as the change of temperature or a command from the controller to an actuator. And also, low data rate helps to prolong the battery life.

(3) Number of nodes. The capacity of network is determined by the number of nodes, and ZigBee has up to 254 nodes, the largest among the three. It meets the application demand of more and more sensors and actuators in a greenhouse.

(4) Current consumption. ZigBee has the lowest current consumption, 30 mA, while Wi-Fi, 350 mA, and Bluetooth, 65~170 mA. It also greatly helps to prolong the battery life.

(5) Battery life. ZigBee chip has the longest battery life, a few months or even years.

As a whole, ZigBee technology offers long battery life, small size, high reliability, automatic or semi-automatic installation, and, particularly, a low system cost. Therefore, it is a better choice for greenhouse monitoring and control than other wireless protocols.

OUR WIRELESS SOLUTION FOR GREENHOUSE

Overview of the solution

As shown in Fig.1, wireless sensors, such as temperature sensor, humidity sensor, light sensor and so on (integrated with PIC 16F877 and ZigBee module), collect the environmental information and transmit it to hand-held controller (HHC) (integrated with ARM MCU and ZigBee module). In HHC, the data is stored and displayed on the LCD. After the data being dealt through control algorithm, the HHC sends control commands to the actuators (also integrated with PIC 16F877 and ZigBee module). The actuators accomplish the actual control task. All the wireless nodes are based on ZigBee module.

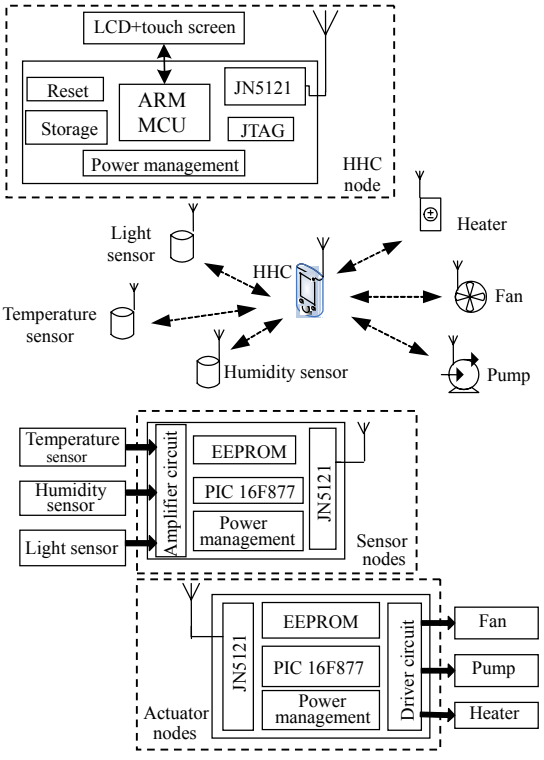


Fig.1 Overview of the proposed wireless solution for greenhouse monitoring and control

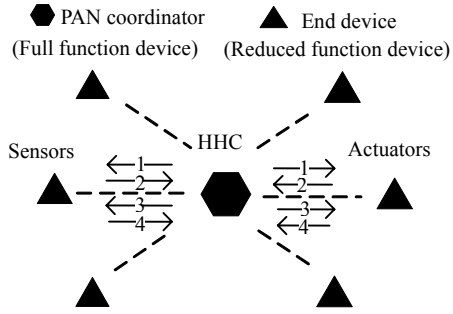
We designed the nodes based on JN5121 module produced by Jennic Company (Jennic Ltd., 2006a). The JN5121 is the first in a series of low-power, low-cost IEEE802.15.4 compliant wireless microcontrollers, combining an on-chip 32-bit RISC (Reduced Instruction Set Computing) core, a fully compliant 2.4 GHz IEEE802.15.4 transceiver, 64 kB

ROM and 96 kB RAM. The high level of integration helps to reduce the overall system cost. The JN5121 connects upper controller and sensors/actuators through SPI (Serial Peripheral Interface) or parallel.

Network establishment

Sinem Coleri Ergen (2004) summarized three types of topologies of ZigBee: star topology, peer-to-peer topology and cluster tree topology. In the star topology, the communication is established between devices and a single central controller, called the PAN (Personal Area Network) coordinator. The PAN coordinator may be mains powered, while the devices are most likely battery-powered. Each star network chooses a PAN identifier, which is not currently used by any other network within the radio sphere of influence. This allows each star network to operate independently.

In our project, we established the network according to the star topology. As shown in Fig.2, once the HHC (FFD, Full Function Device) is activated for the first time, it establishes its own network and becomes the PAN coordinator. Then it initializes the hardware, stack and application variables, choosing an unused PAN identifier of zero, and broadcasting beacon frames to sensors and actuators (RFD, Reduced Function Device). Sensors and actuators receiving a beacon frame may request to join the network. The HHC will add them as a child device in its neighbor list and return a response. The sensors and actuators will add the HHC as its parent in their neighbor list and return an acknowledgement. The HHC monitors all network nodes in real-time, maintaining the network information database PIB (PAN Information Base).



1: HHC broadcasts beacon frames to sensor/actuators; 2: Sensor/actuators request to join the network; 3: HHC returns a response to sensor/actuators; 4: Sensor/actuators return an acknowledgement to HHC

Fig.2 Network establishment

Nodes software system

The main task of the software system is the communication among the wireless nodes. It is divided into two parts, the initialization process and the information processing process. We designed the software system according to the Reference Manual: JN5121-EK000 Demonstration Application (Jennic Ltd., 2006b). In each node's code, interrupts are used extensively to synchronize operation, which allows the device to put the CPU to sleep for long periods whilst nothing is happening.

Fig.3 shows the initialization of the communication. Once the coordinator (HHC) creates PAN, it sends out regular beacons. After the sensor/actuator nodes successfully receive and verify the data frame and MAC command frame, they send back an acknowledgement to the coordinator. Sensor/actuator nodes then go to the sleep mode. The coordinator converts its host-slave role with the sensor/actuator nodes. The coordinator then works under the slave mode, waiting for responding to a request for connection. At this time the sensor/actuator nodes work under the host mode, waiting for being demand-awaken and initiating a connection request. After the initialization, the sensor/actuator nodes work under the sleep mode, refusing any connection request. This design greatly reduces the power consumption of the sensor/actuator nodes. Furthermore, because the sensor/actuator nodes are demand-activated, it effectively prevents the illegal connection request of other sensors/actuators, thus provides a safety and reliability for the communications between the coordinator and sensor/actuator nodes.

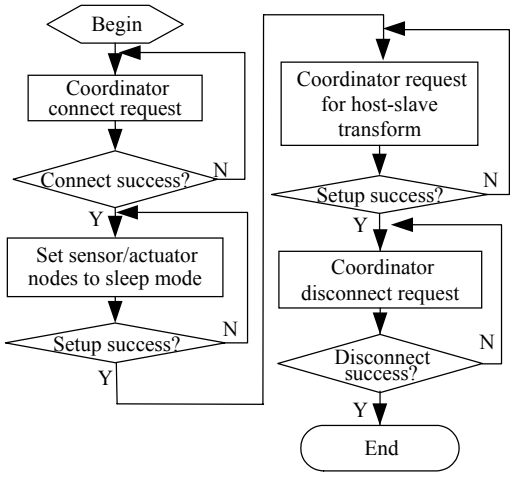


Fig.3 Initialization of the communication

The information processing is further divided into two sub-processes. Fig.4a shows the information processing between the coordinator and the sensor nodes. When the sensor nodes detect changes of the monitoring parameters, they primarily deal with the information, initiate the connection request and transmit the dealt information to the coordinator. Fig.4b shows the information processing between the coordinator and the actuator nodes. When the actuator nodes receive an interrupt request from the coordinator, they are activated and begin to receive a command from the coordinator. After a transmission and a reception are completed, the sensor nodes and actuator nodes return to their sleep modes. It has been proved in engineering testing that the wireless sensor/actuator nodes are under a sleep mode for 99% of the whole time, and the mathematical expectation of the power consumption may be as low as 30 μA.

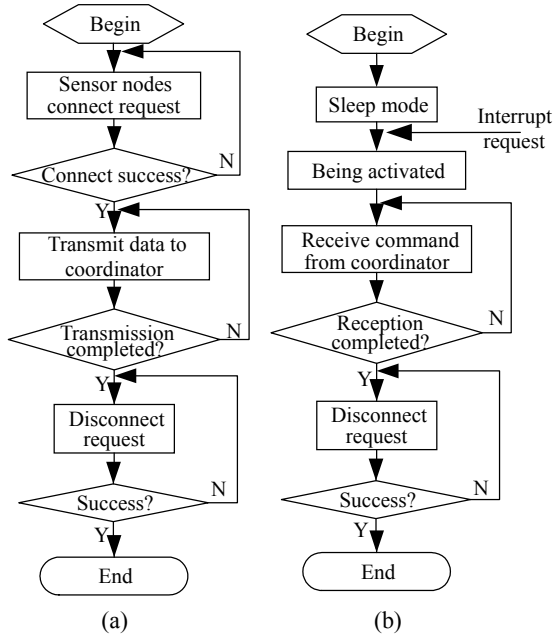


Fig.4 Information processing between coordinator and sensor (a) and between coordinator and actuator nodes (b)

CONCLUSION

In this study, we discussed the wireless solution of greenhouse monitoring and control system based on ZigBee technology, and designed the wireless nodes, network establishment and software system. With the capabilities of self-organizing, self-configuring, self-diagnosing and self-healing, the ZigBee-based monitoring and control system provides nearly unlimited installation flexibility for transducers, increases network robustness, and considerably reduces costs. The system has been smoothly running in the modern greenhouse of Lishui Academy of Agriculture Sciences, Zhejiang, China, which proved its accessibilities and reliabilities. We, therefore, conclude that the ZigBee-based monitoring and control system can be a good solution for greenhouse monitoring and control.

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