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Environment Monitoring System Research Based on the ZigBee Wireless Sensor Network Technology

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Abstract: An environmental monitoring system based on ZigBee wireless sensor network technology was researched in detail in this paper. Firstly, the technology working principle of ZigBee and its characteristics were introduced, and the characteristics of wireless sensor network and its application advantages were analyzed in comparison with the traditional network. Secondly, the overall scheme of the environmental monitoring system was researched, this system was mainly composed of hardware design, including the terminal node module and the master node module, and software design, and ultimately achieved the construction of the environment monitoring system constitute a based on ZigBee wireless sensor network. Finally, the practicality of the environment monitoring system and its corresponding characteristics were verified through the experiments of two stages. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: ZigBee, Wireless sensor network, Environmental monitoring system, Node, Sensors.

1. Introduction

Wireless sensor network, as one of the most important research technologies of the 21st Century, is being researched in the initiative application stage. It is as elf-organized network system with multihop, and is composed with wireless telecommunication as well as numerous wireless nodes with sensors deployed in the monitoring area. Its role is in cooperation with perceiving, collecting and processing the information of objects-perceived in the network coverage area and transmitting it to observers [1].

These sensors with low-energy consumption and communication ability are scattered in the monitoring area and coupled with the physical world to gain unprecedented perception precision by amounts of high density deployment.

The sensor network is being used in various fields of environmental monitoring, high-precision agriculture, military reconnaissance and so on, and its potential application value is being constantly explored. Meanwhile, the ultimate goal of acquiring the addressing capability of ubiquitous information transparently by mankind ultimately also needs the support of the Wireless sensor network technology. And this technology has already become the research focus of industry and academia [2].

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2. Technical Principles of ZigBee

ZigBee is a bi-directional wireless communication or network technology with close range, low complexity, low power, low data rate and low cost, which operates on the wireless principles of the Institute of Electrical and Electronics Engineers 802.15.4 (IEEE 802.15.4) for utilization in the aspects of networking, security and software applications [3-5]. It is fit for bearing service of low data flow, embedding various devices and supporting functions of geo-location simultaneously. The devices compatible with ZigBee have mesh topological structure, which can extend the transmission range of single nodes. The target market of ZigBee aims at the wireless communication application with low consumption and low cost in industry, family and medical science, etc. The structure and function of ZigBee is shown in Fig. 1.

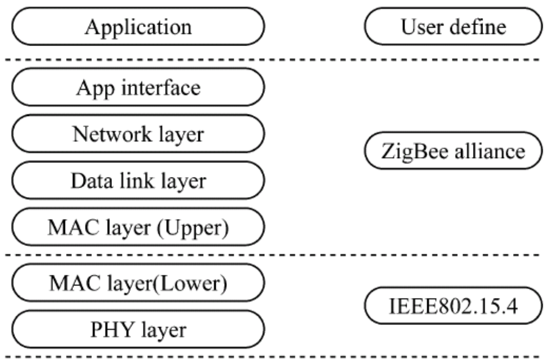

Fig. 1. The structure and function of ZigBee.

3. ZigBee Technical Characteristics

ZigBee is an emerging close-range wireless network communication technology with the following characteristics:

1) Power saving: Two standard double A type batteries can last from six to twenty-four months when used in the various operating modes of ZigBee technology.

2) Communication-reliability: ZigBee avoids the competitions and conflicts with the utilization of collision avoidance mechanisms of Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) and a reserved special time slot for constant band-width communication services. Each data package needs the confirmation of the receiver under the data transmission mechanism with complete ascertainment of a Media Access Control (MAC) layer.

3) Excellent functions of self-organization and self-repair:

a) Self-organization function: Other nodes can be perceived by the network node without manual intervention, connected by the definite relationships and forming the network structure.

b) Self-repair: If a node is added or deleted, its position would be changed, and the node could not work normally. And the network has the ability of self-repairing and adjusting the network topology structure correspondingly without manual intervention to ensure the entire system can still work properly.

4) Low cost, low complexity of devices and free patent of ZigBee protocol are the main factors to reduce the device's cost efficiency. The operation band of Zombie is flexibility with unlicensed 2.4 GHz band without payment.

5) Huge capacity. At the most 254 subordinate devices and one major device can be contained in a ZigBee network, and more than 200 ZigBee networks can coexist in a sector.

6) Data Security. ZigBee provides the functions of data integrity and authentication, applies Advanced Encryption Standard (AES) 128 encryption and confirms the security attributes of every application respectively [6].

4. Features of Wireless Sensor Network

Wireless sensor network consists of sensors, objects-perceived and observers. The objects-perceived is the monitored target of the observer and the observer as the network users that receive and use the perceived information. The wireless sensor network integration is composed of the sensors, data processing unit and tiny nodes of communication module, which self-organize the network. The self-organized network management features of the wireless sensor network are determined by the characteristics of sensor nodes and deployment environment. Compared with traditional networks, the wireless sensor network owns lots of its characteristics as follows, which determine its application advantages in many aspects [7].

1) Limited power energy: Energy of electricity supply is limited by the module volume of nodes and avoids the inconvenience of manual battery replacement.

2) Limited communication capacity: Influenced by the limitation of antenna and power, complex natural environment and node density, the coverage range scale of communication is tens to hundreds of meters with small and unstable bandwidths.

3) Limited calculating ability. Calculating ability of the sensor is limited by the capacity of embedded processors and memories.

4) Enormous numbers of sensors, wide range of distribution and high density of nodes: Sensor nodes in sensor networks own high density of sensor nodes, which may reach hundreds, tens of millions, or even more. Besides, the sensor networks can be distributed within a vast geographical area.

5) Strong network dynamics: The three factors of sensors, objects-perceived and observers in network all may have mobility, and often there is a new node added or an existing node failure, the

abilities of nodes will vary with utilization. Therefore, the sensor networks have strong network dynamics.

6) Data-centric distribution of cooperative computing: The main objective of traditional networks was point-to-point communication, however, the sensor network primarily targets the data transmitted to the receiving nodes, and cooperated completed one or several application targets with the help of the limited shared resource, such as the energy of sensor and bandwidth of communication channel.

5. The Overall Program of Environment Monitoring System

The entire system consists of a monitoring center and a ZigBee network, which is shown in Fig. 2. It is a hierarchical network structure with sensor terminal nodes at the bottom, and then orderly ZigBee master node and monitoring center. The monitoring center is a computer, which is used for illustrating the environmental monitoring data and sending commands to the network. The terminal node and master node forming the ZigBee network that takes charge of collection of environmental data. The ZigBee network consists of ZigBee master nodes and ZigBee terminal nodes, and is responsible for the collection of environmental data. Each network must have a ZigBee coordinator responsible for initiating the network and its management and maintenance, which includes assigning a network address to new equipment, management of the nodes and the distribution and update of the network security key. In order to avoid nodes joining any network and resulting in the power consumption of the network nodes being unevenly distributed, the interior network is divided into a number of small internal star networks in this system, and each star network is defined as a group. The central node of the star network integrates processing the upload information of terminal equipments, and sends the data to the ZigBee master nodes. The ZigBee network monitoring center has two kinds of connection, and usually the coordination and the monitoring center is connected through the serial port directly [8-9]. When the monitoring center is unsuitable after being used in the field for a long time, the General Packet Radio Service (GPRS) can be used to send data to the monitoring center with GPRS receiver devices.

The monitoring center is in charge of monitoring of sensor node working condition and state, displaying the original address data, data collected by sensors and its variation trends and according to them tasks of the nodes are adjusted. The states of nodes include rest power, working condition of sensor and communication components. Duty period can be adjusted in a timely manner and redistribution tasks thus avoid the nodes' premature failure and extend the entire lifetime of the network by monitoring the state of sensors [10]. Now the residual energy information of the nodes was determined mainly by the working voltage of the nodes. If the voltage value is too low, the node reads the reliability of the data of the sensor as reduced, and therefore needs to prolong the sleep time of the low voltage node and reduce the sampling frequency.

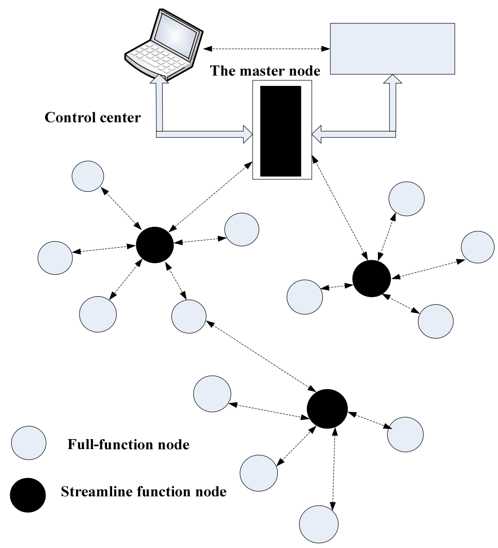

Fig. 2. The network structure of environment monitoring system.

5.1. Hardware Design

1) Terminal nodes module.

Terminal nodes should have the features of small size, low power consumption and high adaptability, and their main function is mainly to accomplish the acquisition, processing, and sending of the parameters such as temperature and humidity of the environment, light intensity and so on. Wireless Sensor Node (WSN) is composed of sensor module, processor module, wireless communication module and the power supply module, and the Fig. 3 shows the structural diagram of the node hardware. The processor module and wireless communication module use a CC2430 chip, the power supply adopts a solar rechargeable battery module, and the sensor module employs the temperature humidity sensor and photoconductive resistance. During the process, photosensitive resistance outputs analog signal, then inputs it to Analog to Digital Converter (ADC) of Micro Controller Unit (MCU) -12 bits, and then input to MCU. Temperature and humidity sensors collect digital signals which are put into MCU by the Input/Output (I/O) ports, and then the signals are modulated to carrier waves and sent to the primary nodes by Offset Quadrature Phase Shift Keying (O-QPSK) from the antenna [11].

CC2430 is a chip system solution of 2.4 GHz IEEE802.15.4/Zigbee Termination Multiplexer (TM) produced by Texas Instruments (TI) Corporation, which integrates the radio frequency front-end of ZigBee, internal storage, and microcontroller, and contains an 8-bit 8051MCU, owns 32/64/128k programmable Flash and 8k (Random-Access Memory) RAM, also contains ADC, Timer, Advanced Encryption Standard (AES) 128 safety co-processor, WDT (watch-dog timer), circuit of POR (Power-On Reset) circuit and PFD (Power-Fail Detection) circuit, 32 kHz crystal dormancy mode timer and 21 programmable I/O pins. The interfaces of P0 and P1 are 8-bit ports completely, but P2 only 5-bit ports can be available. The bits and bytes of a group of SFR registers can make these pins as a general I/O port or periphery I/O port of connect ADC, timer or Universal Asynchronous Receiver/Transmitter (UART) parts by setting software [12].

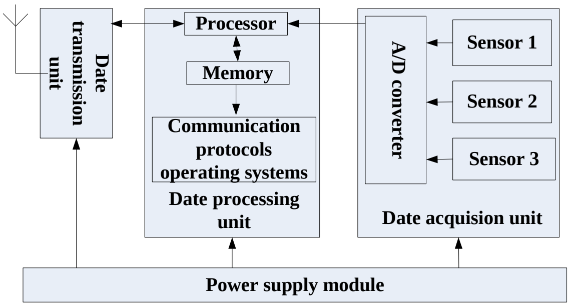

Fig. 3. Terminal node design.

2) The Master Node Module.

The diagram of the master node hardware design circuit is shown in Fig. 4 the microprocessor is the C8051F series microcontroller, which was produced by Cygnal Corporation. The C8051F31X series is a fully system-on-chip integrated mixed signal, which has a Console Interface Program (CIP)-51 inner core, which is completely compatible with the 8051 instruction set. It gathers almost all the analogs and digital peripherals and other functional units that constitute a single-chip microcomputer data acquisition and control system in the single chip microcomputer.

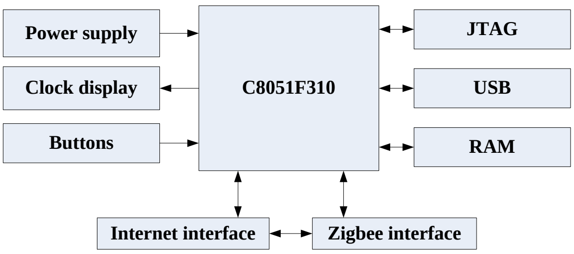

Fig. 4. The master node hardware design.

These peripherals or functional units include: ADC, PGA(Programmable Gain Amplifier), Digital to Analog Converter (DAC), Voltage Comparator (VC), Voltage Reference (VR), Temperature Transmitter (TT), System Management Bus / Inter－Integrated Circuit (SMBus/I^{2}C), UART, Serial Peripheral Interface (SPI), Timer, Principal Components Analysis (PCA), Internal Oscillator (IO), WDT, PWU (Power Monitoring Unit) and so on. The high integration of these peripheral components provide a great convenience in designing a small volume, low power consumption, high reliability and high performance single chip microcontroller application system, at the same time, also greatly reducing the cost of the integrated system [13-14]. Due to the coordinator having been in a state of receiving & transmitting, it uses an external power supply. In designing the hardware, and Liquid Crystal Display (LCD) screen and Joint Test Action Group (JTAG) interface are added, making it convenient for data checking and computer communication. In addition, the added Internet network interfaces are also convenient for remote monitoring.

5.2. Software Design

After the coordinator initiates the network, the sensor nodes join the network and bind coordinator, and press the keys to select the group it wants to join. The default set temperature, humidity, and illumination are collected and transmitted per 30 seconds, and the battery voltage is per 60 seconds. The data is eventually sent to the coordinator, and then uploaded to the monitoring center by the coordinator. The monitoring center also can send the commands to the monitoring situation of the network, and the terminal equipments will inquire whether there exists message or not after waking up in hibernation each time, if one exists it will execute immediately. For example, if the monitoring center sends the command to stop collecting the temperature data, all the terminal equipments will receive the command coming from coordinator after wake up, and then stop collecting the temperature data.

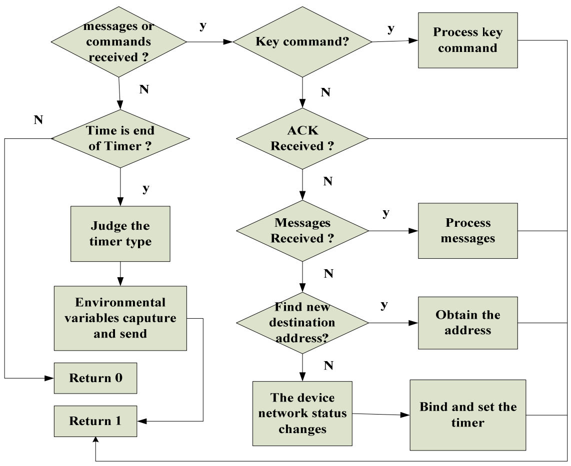

Fig. 5. The user task flow chart.

After the hardware system is powered, the terminal equipments will execute the master scheduling function, which firstly resets all the components and starts the system status detection function, and transfers the initialization module to initialize the MCU and peripherals and so on, and then gets into the task cycle. The tasks include hardware interface, network layer, application access, user defined task process and so on. The user defined task process is shown in Fig. 5. If no event occurs, the system will remain in a sleep state, when one event occurs the system will be in working condition, and process the response event. After processing, the system will continue to sleep. For example, the timer event is defined in order to allow the system timing sensor sampling environment. If the timed event is finished, the system will control the set status word. If the status word is not set the system will go back to a sleep state. The types of data collected in a control status word definition currently can be defined: temperature, humidity, light intensity and battery voltage. The terminal equipments can also receive the control commands that come from the master nodes, such as to start or stop collecting data, the set acquisition time and so on.

The keystroke event is mainly to deploy the node network and functions, which includes accession network, address binding, selection collected data, encryption functions and so on.

6. Experimental Verification

The application of wireless sensor to obtain crops environment information in greenhouse, the current consumption of terminal nodes, and whether the nodes have reliable energy supplement or not will affect the greenhouse life cycle of wireless sensors. In order to verify the practicality of the system equipments, the experimental method includes two stages. The experiment verified the active state power management, which includes collection, processing, sending and receiving, and tested the application of software design under the key network conditions.

The first stage of the experiment was done in a laboratory environment. Two terminal sensor nodes were used to communicate with two corresponding network routers, and build a small ZigBee network through the coordinator in this experiment.

The second stage of the experiment was finished in the actual production environment of Greenhouse Horticulture Center of Jiangxi Agricultural University. In this experiment, the application of a wireless sensor node captured some data of greenhouse air and soil temperature, relative humidity and solar radiation of the other data. In order to test the device node discovery and realize the function of join the ZigBee network, two routers were applied between the coordinator, which was located control room, and the sensor nodes, which were actually two run routing program in the terminal sensor node routing device).

The first stage of the experiment was to verify the software design, which includes a description of the state machine and a low duty cycle power management platform model. For example, the batteries charge after being initialized, and the situation of the electricity running. At this stage to quantify and measure operation and processing of various states usually require a lot of power, especially when the network is running, find and join the process of sensor nodes.

Experimental operation in the first stage is established under special conditions, it verified that the system was running based the ZigBee, the nodes obtained the important parameters of rechargeable batteries power from surroundings. In order to obtain accurate and representative of the power supply voltage and current consumption waveforms, this verification test must be done in the laboratory. In order to achieve the efficient operation of the site, a variety of low-power analog sensors were used in this experiment, there were as follows: three temperature sensors for measuring air temperature, and a two-way roads soil temperature; a relative humidity sensor and two solar radiation sensors.

Fig. 6. shows a power supply current consumption, from the figure can see during the routing node the router join the process at its initial 2 seconds, sensor nodes operation as expected, the router device routes the data from the terminal sensors to the coordinate and vice versa. Besides, the power management system is running at any stage, its current consumption is about 50 mA, which needs to be replenished energy from surrounding environment.

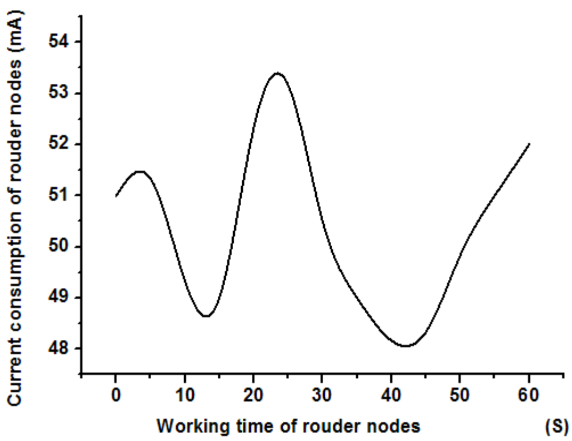

Fig. 6. Power supply current consumption of the router nodes.

Fig. 7 shows the battery voltage graph of terminal sensors equipment located in the greenhouse. Low-power batteries were powered by solar panels, and the panels are also used to measure the solar illumination. During the 4 hours test period, the batteries keeps on charging mode until the batteries voltage reach approximately 4.2 V, at this time, the software program keeps the batteries in dynamic conditions of providing a trickle charge mechanism. Taking into account the actual needs of production and the application of sensors, the data was received by coordinator at the 60 seconds interval. As can be seen from the Fig. 6 that the average batteries voltage is no less than 3.9 V during the data transmission process at per 60 seconds.

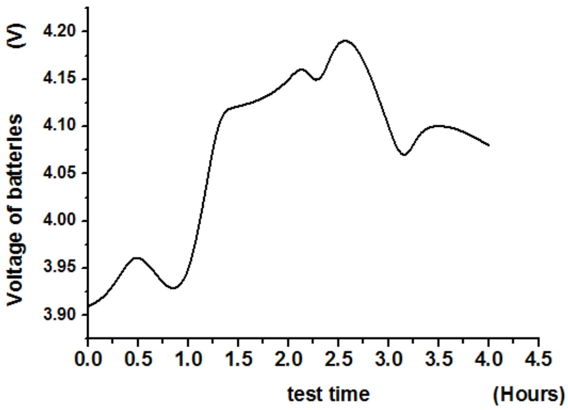

Fig. 7. Battery voltage waveform of test time.

The experiments were carried out in a laboratory environment and the greenhouse horticulture center field environment, through the laboratory testing as well as the power supply and the power consumption of greenhouse nursery field operation, which verified the active state power management, temperature, humidity and real-time collection and display of light intensity, namely, that is implemented wireless information collection based on the ZigBee protocol. Through the field operation and tests, the power supply is steady, and the terminal nodes are reliable.

7. Conclusions

This paper shows the feasibility that based on ZigBee wireless sensor networks through two-stage tests. Meanwhile, in order to achieve reliable and accurate operation of nursery greenhouse field environment, the power management is rather important. Sensor network nodes via solar rechargeable batteries and replenish energy from environment. In this research, the software design by the nodes to correct solution these problems, and the correctness of software program method was test in special condition. And achieved the greenhouse environment monitoring system that based on ZigBee wireless sensor networks, the system is able to efficiently capture the greenhouse environmental parameters, including temperature, humidity, light intensity, and has characteristics of low power consumption, high reliability and power supply stability. This paper combined with some technologies to achieve a common environment monitoring system based on the ZigBee wireless sensor network technology. The system can be used to real-time monitor some kinds of interested parameters within the measured environment at any time, and to solve the many disadvantages of the traditional monitoring systems effectively. Combining part of the basic theory of knowledge and the specific system design methodology study and discussion in detail, and further promoting its wider development and application in wireless research based on the effective understanding of the principles and characteristics of wireless sensor network.

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