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RESEARCH ARTICLE

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Forest fire detection system based on a ZigBee wireless sensor network

Abstract Compared with the traditional techniques of forest fire detection, a wireless sensor network paradigm based on a ZigBee technique was proposed. The proposed technique is in real time, given the exigencies of forest fires. The architecture of a wireless sensor network for forest fire detection is described. The hardware circuitry of the network node is designed based on a CC2430 chip. The process of data transmission is discussed in detail. Environmental parameters such as temperature and humidity in the forest region can be monitored in real time. From the information collected by the system, decisions for fire fighting or fire prevention can be made more quickly by the relevant government departments.

Keywords wireless sensor network, fire detection, network system, network node, data transmission

1 Introduction

Forests are part of the important and indispensable resources for human survival and social development that protect the balance of the earth ecology. However, because of some uncontrolled anthropogenic activities and abnormal natural conditions, forest fires occur frequently. These fires are among the most serious disasters to forest resources and the human environment. In recent years, the frequency of forest fires has increased considerably due to climate change, human activities and other factors. The prevention and monitoring of forest fires has become a global concern in forest fire prevention organizations. Currently, forest fire prevention methods largely consist of patrols, observation from watch towers and lately satellite monitoring (Lai, 2004; Huang et al., 2005). Although observation from watch towers is easy and feasible, it has several defects. In the first place, this method requires many financial and material resources and a trained labor force. Second, many problems with fire protection personnel abound, such as carelessness, absence from the post, inability for real-time monitoring and the limited area coverage. The scope of application of satellite detection systems is also restricted by a number of factors, which reduces its effectiveness in forest fire detection. For example, a satellite monitoring system has a long scanning cycle and the resolution of its saturated pixel dots of images is low. Another problem is cloud layers may mask images during the scanning period and the real-time mathematical quantification of fire parameters is very difficult to achieve (Shu et al., 2005; Yu et al., 2005; Calle et al., 2006). Given these shortcomings of traditional monitoring, we suggest the ZigBee wireless sensor network technology and explain its application as a monitoring system. This system can monitor real-time related parameters, e.g., temperature, relative humidity, and send the data immediately to the computer of the monitoring center. The collected data will be analyzed and managed by the computer. Compared with the normal meteorological information and basic forest resource data, the system can make a quick assessment of a potential fire danger. The analytical results will then be sent to the relevant department as the policy-making basis by which the department will make the decision of fire fighting or fire prevention.

2 Main parameters of forest fire monitor

Three factors compose the basis of a forest fire: the fire source, environmental elements and combustible material. A forest fire usually occurs as the result of their combined effects (Song et al., 2006). According to the Canada Fire Weather Index Forecast Model, the moisture content of the combustible material plays an important role in forest fires, which means the probability of forest fires depends on the moisture content (Tian et al., 2006). Therefore, the moisture content of combustible materials is a major point of assessment and predicts whether a fire

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will take place. The moisture content has much to do with relative humidity in the atmosphere, air temperature, wind and similar factors (Shu et al., 2003; Zhang, 2004). Water evaporation can be directly affected by relative humidity. At the same time, the physical properties of combustible materials can be changed indirectly by air temperature. Thus, relative humidity and air temperature are regarded as the two main factors which affect the moisture content of the fuel. Therefore, to reflect the moisture content indirectly, these two parameters are the main objects of our investigation, which should provide an important basis for the prediction and monitoring of forest fires. Certainly, forest fires are also caused by other factors, such as the active degree of thunder and lightning above the forest, human factors, wind speed, and condition of area vegetation. However, these factors will be ignored in our discussion.

3 Application of ZigBee wireless sensor network in a forest fire monitoring system

A wireless sensor network, which combines computer and communication technology with the technology of a sensor network, is considered to be one of the ten emerging technologies that will affect the future of human civilization. This network is composed of numerous and ubiquitous micro sensor nodes which have the ability to communicate and calculate. These nodes can monitor, sense and collect information of different environments and various monitoring objects cooperatively.

ZigBee is a low-rate, low-cost and low-power kind of short range wireless network communication protocol. Compared with other wireless technologies, ZigBee has unique advantages of safe and reliable data transmission, an easy and flexible network configuration, low equipment costs and long-lasting batteries. Thus, it has great development potential and a promising market application in the field of industrial control.

By applying a wireless sensor network based on ZigBee to a forest fire monitoring system, information such as temperature and humidity at any part of the forest covered by the network could easily be collected, dealt with and analyzed at any time. In addition, the system can be extended significantly, the cost of equipment maintenance could be reduced and the whole system could be optimized.

3.1 Forest fire monitoring system based on ZigBee wireless sensor network

A ZigBee wireless sensor network system includes sensor nodes, gateways (routers) and a monitoring host computer. To decrease the loss of energy and data packets, a cluster-tree network topology structure (Tillett et al., 2004) (shown as Fig. 1) is applied in this design. Sensor nodes fitted with microprocessors of low processing capacity are distributed randomly in the forest and nearby areas to collect fire monitoring parameters such as relative humidity and atmospheric temperature (Zenon and Fady, 2005). Depending on the part the different sensor nodes play in the whole network, they are divided into three categories: ordinary bottom nodes, cluster heads and network coordinators. Data collected is transmitted to its own cluster head by an ordinary bottom node. A cluster head mainly handles data fusion and data packet transmission. Via the cluster head, data collected by ordinary bottom nodes in the cluster can be fused and transmitted to the nearest network coordinator and data packets transmitted by the network coordinator can be broadcast to related clusters. A network coordinator mainly deals with basic network

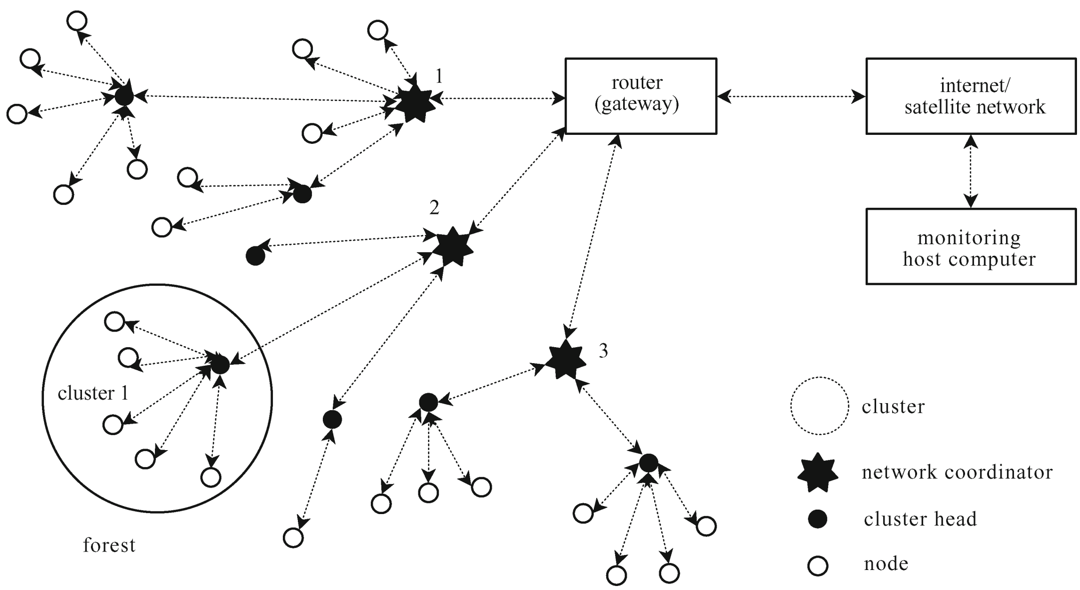

Fig. 1 Structure of a wireless sensor network for forest fire detection based on ZigBee technique

management functions such as network configuration, equipment registration and access control. Data information can be transmitted to routers by wireless communication. When receiving data, routers establish a local database and then transmit the data to the monitoring host computer via internet, which provides a decision-making basis for forestry or fire prevention departments.

3.2 Structure of the sensor node

The sensor node is a basic unit and platform of the wireless sensor network. A sensor node is commonly composed of a sensor module, a processing module, a wireless communication module and a power module. Figure 2 shows the structure of the sensor node.

The sensor module is responsible for data analog-digital conversion and collecting parameters such as relative humidity of the atmosphere and air temperature. The processing module is responsible for controlling the operation of the whole sensor node and saving and coping with data collected by its own node and the binary information transmitted from other nodes. The wireless communication module is responsible for communication with other nodes and exchanging control information and receiving or transmitting data. The power module supplies power for the other three modules and drives the nodes, making it the key factor for the effective operation of the network (Ren et al., 2003).

4 System hardware design

The hardware design of network nodes, including sensor nodes and router nodes, is the basis of the wireless sensor network structure.

4.1 Sensor node design

Figure 3 shows the circuit principle of a sensor node.

A CC2430 chip, recently launched by the Chipcon Company, is the core chip used in the hardware design of nodes. It is an SoC CMOS chip, embedded with a high-performance and low-power microcontroller chip 8051, an integrated ADC of 14-bit analog-digital conversion and a 2.4 GHz RF wireless transceiver that conforms to the IEEE802.15.4 standard. This chip has good wireless receiving sensitivity and excellent anti-interference performance. When under a receiving and emitting mode, the loss of current is less than 27 or 25 mA respectively. The CC2430 chip requires only a very short time in changing its mode from sleep to an active mode and is especially suited for forest fire monitoring applications which require long-lasting batteries.

SHT11, an integrated digital sensor for relative humidity and temperature with a I2C bus made by the Swiss Sensirion Company, is used in the sensor node. This sensor has some of the most advanced functions such as digital output, is alignment- and calibration-free, has auto-dormancy, and can be completely submerged in water. Its size is extremely small (7.5 mm × 5 mm × 2.5 mm) similar to a match head. The SHT11 requires a supply voltage of 2.4–5.5 V. The chip also has four free NC pins and a 10 kΩ pull-up resistor, access to the DATA bus and a 100 nF filter capacitor connected to a VDD and GND.

A DS2401 chip is treated as a unique identifier memory for hardware nodes. Before use, the unique 64-bit registration code is marked on a DS2401 ROM, including an 8-bit family code, a 48-bit sequence code and an 8-bit CRC. Any DS2401 chip, produced by the Dallas Company, has a different sequence code. Except for the grand pin, the DS2401 chip has only one function pin which can supply power and deal with input and output.

The power supply for the system is provided by two large-capacity, high-energy alkaline batteries. To assure a stable working state and maintain working characteristics, a MAX1724EZK30 is used in the nodes to keep the working voltage steady.

A TA-XPQ2400-3dBi rubber antenna produced by the ShiDaiChuangXing Antenna Factory is applied in the

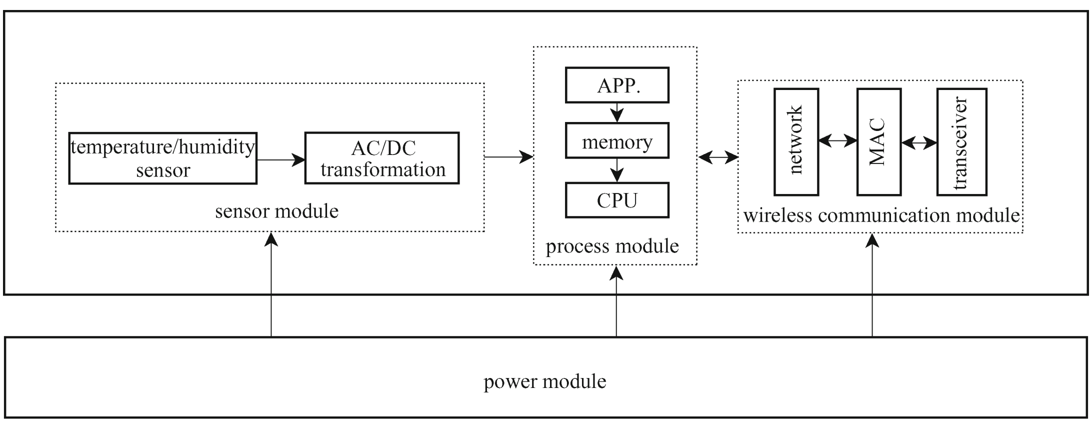

Fig. 2 Structure of a sensor node

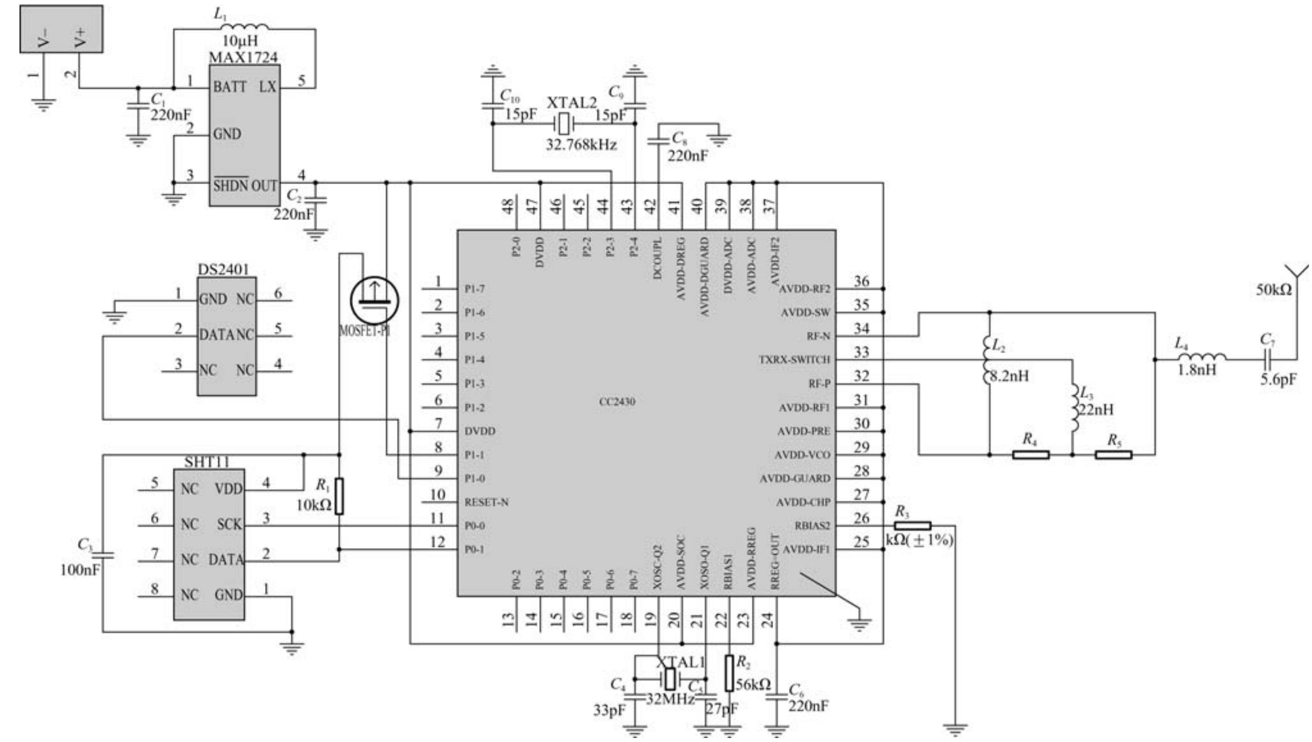

Fig. 3 Circuit diagram of a network node

system. The antenna is 5 cm long, weighs 20 g and is easy to install. Its typical emission frequency is 2.4 GHz.

4.2 Gateway design

The hardware configuration of the gateway (shown as Fig. 4) includes the main processor, a memory unit, an RF receiver and transmission module, a GPRS communication module, and I/O and Ethernet and extension interfaces. Considering the large number of control functions and the large data flow of the gateway, processors with strong processing ability are required. Since the 8051 micro-controller embedded in the CC2430 cannot meet these requirements, a PXA255 processor chip of the Intel Company is installed. It is an RISC processor which integrates a complicated circuit in one chip with high performance and low cost, thus combining powerful functions with the advantages of embedded processors. In the RF receiver module, a CC2430 is still used, through which bi-directional communications with sensor nodes are achieved, data from nodes can be received and control orders can be sent to nodes. A CMS91 module made by the Cellon Company is used as GPRS module. As the interface between the gateway and the internet, this GPRS module deals with sending data to the Internet and receiving control information from the Internet.

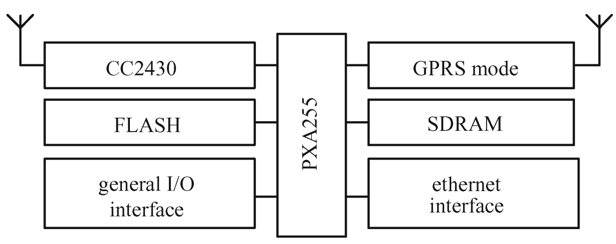

Fig. 4 Structure of the gateway system

5 Data transmission process

To deliver data transmission inside the ZigBee network in this design, a system of active requests for information by the monitoring host computer and passive responses by the sensor nodes is used. Figure 5 shows the data transmission process.

When the monitoring computer, operated by a telecommunications worker, sends an order to inquire about the state of forest temperatures and humidity, the order is transmitted to the router via the internet. The router then scans the routing tables according to the order and decides the target coordinator, which then broadcasts in the attached cluster branch to activate the target cluster head. The cluster head broadcasts towards its member nodes to activate the dormant nodes to carry out data communication. After receiving the data collected and sent by the nodes, the cluster head integrates and returns the data to the monitoring host computer along the original line. If the target network is not found or not connected, the cluster head will desert the data packet and generate a report to the monitoring host computer. Most nodes in

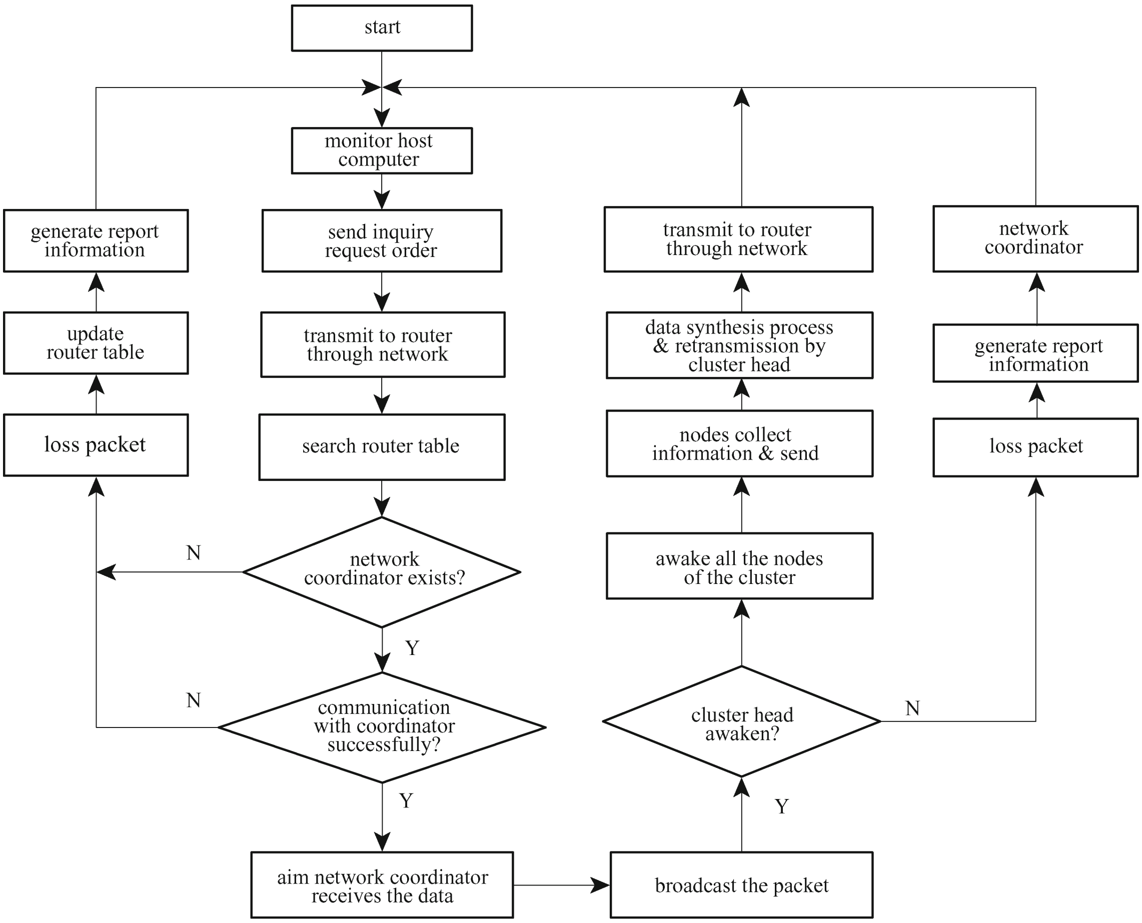

Fig. 5 Flowchart of data transmission

the system are in a dormant state to save energy and extend the lifetime of the network.

6 Conclusions

Wireless sensor networks are increasingly applied in the field of environmental and ecological monitoring. Especially in difficult and harsh environments, it has advantages that traditional monitor systems lack. In addition, wireless sensor technology has a broad application background in the field of real-time forest fire monitoring. But given the complexity and peculiar features of the forest, the system has not been extensively applied in practical forest fire monitoring. To monitor temperature and humidity in the forest in a more timely and precise way, we pointed out unique advantages of safety in data transmission, flexibility in building the network, and low cost and energy requirements for a forest fire monitoring system based on a ZigBee wireless sensor technology that we designed. The topology structure of the system is an adaptation of a cluster-tree. Compared with a reticular structure, a cluster-tree structure can be built more easily and the information path takes less memory space. At the same time, the chain structure needs to be stable and its scale is limited, which needs to be improved in future investigations. In other words, we propose this system as a first attempt and complement to existing forest fire monitoring and prevention methods. It provides a solid basis in terms of hardware for the application of advanced wireless sensor network technology. To extend the potential of the system and improve forest fire monitoring technology, the problems of energy consumption, nodes location and clock synchronization need to be addressed in the future. These are some of the remaining problem areas to be considered, before the level of forest fire monitoring can be improved.

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