Design of Intelligent Fire Real-time Sensing and Monitoring System Based on Wireless Sensor Network

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Abstract: With the deepening of research on wireless sensor networks, wireless sensor networks have been applied to the actual environmental monitoring and fire monitoring is one of the important applications. This paper mainly designs an intelligent fire real-time sensing and monitoring system based on wireless sensor network. In order to solve the problem of delay or even missed alarm caused by low-power sensor nodes' inadequate perception ability, this paper proposes a sensor data acquisition algorithm based on time series prediction (TSDC) and a fire identification algorithm based on neural network. Among them, TSDC algorithm reduces the delay of data acquisition caused by the delay of temperature and humidity sensing of sensor nodes. The fire identification algorithm based on neural network provides an intelligent fire identification method. By fusing the temperature, humidity and light intensity collected by sensor nodes, the fire probability under current conditions can be obtained.

1. Introduction

With the development of communication technology, embedded computing technology and sensor technology, wireless sensor nodes with sensing, computing and communication capabilities have been developed [1]. Wireless sensor network (WSN) is a multi-hop self-organized network composed of multiple sensor nodes. It combines sensor technology, embedded technology, distributed information processing technology and communication technology. It can monitor and perceive the environment in real time. It can process the collected information and transmit it to the users who need it.

These characteristics of wireless sensor networks can effectively solve the problems faced by traditional fire monitoring systems. Based on the research of existing fire monitoring technology and wireless sensor network, this paper designs a new fire monitoring system based on predictive wireless sensor network, which can monitor the target area remotely [2-3]. Wireless sensor nodes have the advantages of small size, no wiring, easy movement, installation and maintenance, which greatly improve the accuracy and timeliness of fire monitoring. Aiming at the problems of false alarm, false alarm and early warning delay, a new fire monitoring system based on wireless sensor network is proposed in this paper [4]. The system uses time series based sensor data acquisition algorithm to process environmental parameters, including temperature and humidity. Reduce the alarm delay caused by insufficient sensor temperature and humidity sensing capability of telosb sensor nodes. In order to improve the accuracy of fire early warning, the system uses neural network algorithm as the fire identification mechanism of the system.

2. Design of Fire Monitoring System

The fire monitoring system described in this paper consists of telosb sensor nodes, monitoring host and communication system, as shown in Figure 1. Sensor is the key part of fire monitoring system. Sensing ability of sensor components to the environment is the main factor affecting the timeliness and accuracy of fire monitoring. In this system, telosb sensor nodes are used. Temperature, illumination and humidity values of the environment are collected during the working

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process. Sensirion SHT11 sensor is used to sense temperature and humidity, and Hamamatsu S10871 light sensor is used to sense illumination.

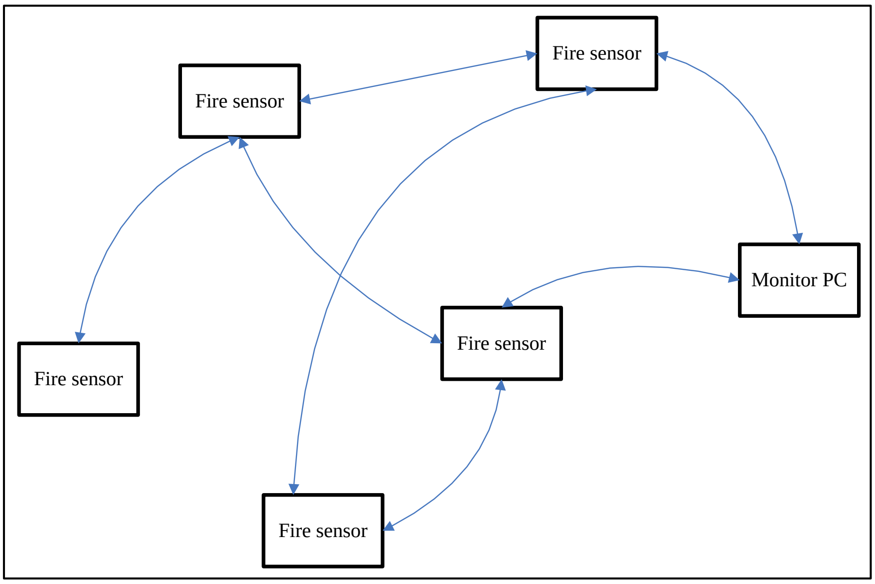

Figure 1. Structure of fire monitoring system

The monitoring terminal of the fire monitoring system is PC. PC and sink nodes communicate with each other through serial port. The sink node first collects the information returned by the sensor nodes in the network and sends the information to the client software of PC through serial port. The monitoring host carries out early warning of the fire by processing the returned data [5]. The timeliness and accuracy of the information processing returned by the control end to the sensor nodes are the ultimate criterion for evaluating the monitoring effect of the monitoring system on the network environment, and also the window for users to feel the feedback signal of the system most intuitively. After the information processing of PC control end, a human-computer interactive interface is constructed to display the status of sensor nodes in the monitoring environment.

In wireless sensor networks, because of the small size of sensor nodes, only batteries with limited power supply can be used for power supply. When using sensor nodes for fire monitoring, the actual monitoring terrain changes in a wide range of tens of meters to hundreds of meters, and there are obstacles between nodes, so the communication between nodes, the energy consumption is greater [6]. Therefore, in order to ensure that the system can work outdoors for a long time and stably, it is necessary to design energy-efficient MAC protocol and application layer protocol as well as optimized network topology.

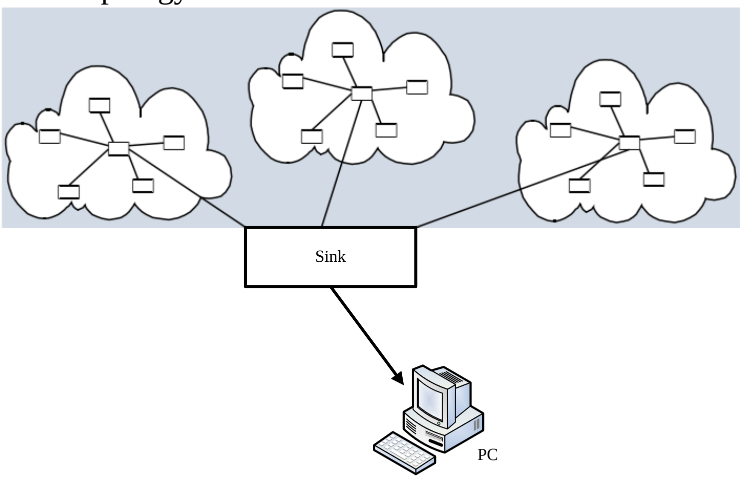

Figure 2. Network structure of fire monitoring system

In sensor networks, the energy consumption of wireless communication module of sensor nodes in the idle state is equivalent to that in the sending and receiving state, so only when the communication module of sensor nodes is closed can the energy consumption of wireless communication module be greatly reduced. Consider selecting some nodes in the network as backbone nodes according to certain mechanism, opening its communication module, and closing the communication module of non-backbone nodes [7]. A connected network composed of backbone nodes is responsible for the data exchange of sensor nodes. This not only ensures the original coverage of the data communication, but also can greatly reduce the energy consumption of the network nodes, as shown in Figure 2.

3. Sensor Data Acquisition Algorithm Based on Time Series Prediction (TSDC)

The time series model created by TSDC includes two parts, one is to describe the trend of environmental change and the other is the autoregressive time series with weak stationary zero mean, which represents the error of trend function. Taking the temperature acquisition as an example, in a specific time slice, assuming that the sensor node is at time t, the real temperature value of the acquisition meets the function $F(t)$, the change trend of the function is $m(t)$, and the autoregressive time series of the function is $X(t)$, then the function time series model of the sensor about temperature acquisition is as follows:

$$F(t) = m(t) + X(t)$$

The TSDC algorithm is divided into three parts:

(1) The establishment of sensor node end time series model;

(2) Sink terminal data prediction;

(3) Sensor nodes feedback on prediction models.

In this paper, in order to speed up the establishment of node prediction model rate and reduce node computing complexity. The trend function $m(t)$ uses the linear trend function: $m(t) = a + b(t)$ a and b as constants. Firstly, the parameters a and b are calculated by the least 2 multiplication according to the data collected by the nodes. The following formula (2) is used:

$$\sum_{t=1}^{n} \left(a + b \cdot t - v_t \right)^2 = \min$$

Where v_t is the temperature value of the node at time t, the partial derivatives of a and b are obtained in the above formulas respectively.

$$\begin{cases} \dfrac{\partial \left(\sum_{t=1}^{n} \left(a + b \cdot t - v_t \right)^2 \right)}{\partial a} = 0 \\ \dfrac{\partial \left(\sum_{t=1}^{n} \left(a + b \cdot t - v_t \right)^2 \right)}{\partial b} = 0 \end{cases}$$

We can find out the parameters a and b of the trend function.

Trend function $m(t)$ can reflect the change trend of node monitoring value in time slice, but in order to improve the accuracy of $F(t)$ calculation, time series function $X(t)$ should be added to reduce the calculation error of trend function. In the system, we use sliding based time series models, such as formula (4):

$$X(t) = \alpha_1 X(t-1) + \alpha_2 X(t-2) + \alpha_3 X(t-3) + \ldots + \alpha_n X(t-n)$$

However, due to the limited storage space and computational power of the sensor, the time series model with sliding window value of 3 and standard deviation of $b(\omega)$ is established in the system.

$$\begin{cases} X(t) = \alpha X(t-1) + \beta X(t-2) + \gamma X(t-3) \\ X(t) = v_t - m(t) \end{cases}$$

Among them, α, β *and* γ are the arguments of function $X(t)$.

4. Fire Recognition Algorithm Based on Neural Network

In this paper, fire monitoring system is based on the sensor nodes perceived temperature, humidity and light intensity of three factors to judge whether there is a fire in the environment. Because of the uncertainty of fire, the system uses neural network model as the recognition mechanism of fire. When the monitoring host calculates the temperature, humidity and illumination intensity of the environment, this set of values is input into the trained neural network model. The probability p of fire occurrence is obtained and compared with the fire threshold θ set by the system, if $p \geq \theta$, the system determines that there is a fire.

Telosb sensor nodes are sensitive to the monitoring of light intensity, so the system uses the real value of light intensity monitored by the nodes to judge the fire. After calculating the predicted temperature, humidity and real illumination intensity, the three parameters are imported into the neural network model to identify the probability of fire under these parameters. In this paper, a three-layer feed-forward neural network model is used in fire monitoring system. There are three neurons in the input layer, which are the temperature value calculated by TSDC prediction algorithm, the humidity value and the illumination intensity monitored by sensor nodes. There are three neurons in the hidden layer and one neuron in the output layer, and the probability of fire occurring in the input layer is output. As shown in Figure 3.

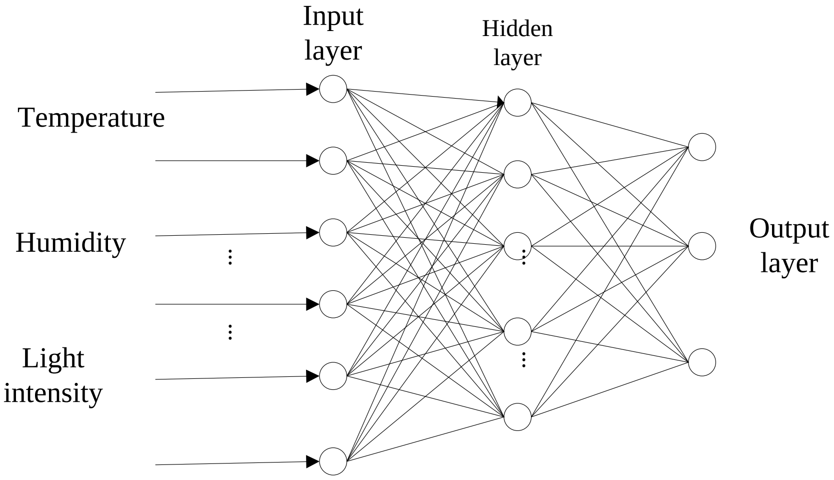

Figure 3. Neural network structure

Before training the neural network model, the weight matrices ω_{ih} and ω_{ho}, threshold matrices b_h and b_o are initialized randomly. When the model is trained according to the training data, the weight matrix will be adjusted continuously, and the threshold value will remain unchanged until the global error:

$$E = \frac{1}{2m} \sum_{k=1}^{m} \sum_{o=1}^{q} \left(d_o(k) - y_o(k) \right)^2$$

Arrive at preset precision or arrive at preset training times.

5. Experimental Analysis

The experiment tests the fire monitoring system under real conditions, including the sensor nodes using TSDC algorithm to monitor the heat source, and the comprehensive test of the system in case of fire. The experiment first compares the perception delay time of heat source with TSDC algorithm and traditional monitoring method. Then the nodes are arranged in the real environment to simulate the fire source by burning different materials. The timeliness and accuracy of the fire alarm system and the test of the client interface are tested. In this paper, the fire monitoring system used in the actual environment monitoring node is telosb node, user interaction client based on Java and TinyOS platform development. The materials used to test the performance of the fire monitoring system include wood, lighter, alcohol and cigarettes.

The characteristic of wood fuel is that the temperature, humidity and light intensity of the material will change obviously in the course of combustion. Lighter is characterized by a shorter duration of the fire source; alcohol fuel in the form of temperature and light intensity changes more obvious, but because alcohol in the combustion process will produce volatilization, so the decline in humidity is not obvious. The characteristics of cigarette burning are light intensity, humidity change is not obvious. Through the monitoring of these materials, the delay time and accuracy of fire monitoring system early warning are statistically analyzed.

Before deploying the fire monitoring system, a single node is used to collect the data of the monitoring environment, including the collection of environmental data under normal conditions and the collection of data when the fire occurs. The data collected by the nodes are trained by the neural network algorithm described above, and the fire identification model suitable for the current conditions is generated. After determining the fire identification mode of the system, the nodes are arranged, and the fire monitoring system is started to monitor the environment.

Firstly, the TSDC algorithm is tested. The nodes use the TSDC algorithm and the traditional direct monitoring method to monitor the heat source. The heat source is boiled water. In the process of water temperature falling from 100℃ to 30℃, the time required for the statistical node monitoring from normal temperature to various temperature points is shown in Figure 4.

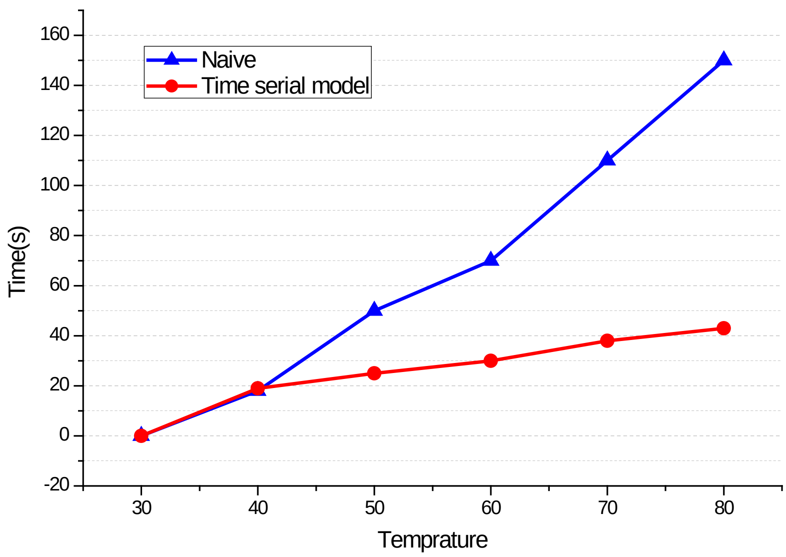

Figure 4. Comparison of monitoring heat sources corresponding time

Wood, lighter, alcohol block and cigarette were used as the fire source respectively. The distance between sensor nodes and fire source was 15 cm. 80 sets of fire monitoring experiments were conducted to calculate the delay time of the system and the recognition rate of the fire under different fire sources, as shown in Table 1.

Table 1. Fire recognition results

Test type	Sample number	Warning delay time/s	Recognition rate/%
Wood	25	29	99
Lighter	25	19	91
Alcohol block	25	22	99
Cigarette	25	36	82

A large number of experiments show that in the fire monitoring system, when the node monitors the fire source which is close to the node, the early warning recognition rate of open fire (temperature, light intensity changes sharply when the fire occurs) is close to 100%, and the delay time of early warning can be controlled within 30 seconds. The recognition rate of dark fire (light intensity changes slightly when the fire occurs) can be controlled at 80%, and the delay time of early warning can be controlled within l min. The recognition rate of fire source monitoring with short duration but obvious fire manifestation can be controlled at 90% and the delay time of early warning can be controlled within 20 seconds.

6. Conclusion

In this paper, the wireless sensor network as the background, focusing on the wireless sensor network fire monitoring system sensor node data acquisition algorithm. In this paper, two main function module algorithms of fire monitoring system are introduced: sensor data acquisition algorithm based on time series algorithm (TSDC) and fire identification algorithm based on neural network. Among them, TSDC algorithm reduces the delay of data acquisition caused by the delay of temperature and humidity sensing of telosb sensor nodes. The fire identification algorithm based on neural network provides an intelligent fire identification method. By fusing the temperature, humidity and light intensity collected by sensor nodes, the fire probability under current conditions can be obtained. Experiments show that the fire monitoring system in this paper has a higher recognition rate of open fire early warning and a shorter delay time control for early warning.

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