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Design Discussion of a Wireless Fire Alarm System Based on Data Fusion Technology

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Abstract: This article explores the design of a wireless fire alarm system supported by advanced data fusion technology. It includes discussions on the basic design ideas of the wireless fire alarm system, hardware design analysis, software design analysis, and simulation analysis, all supported by data fusion technology. Hopefully, this analysis can provide some reference for the rational application of data fusion technology to meet the actual design and application requirements of the system.

Keywords: Data fusion technology; Fire alarm system; Wireless alarm; Hardware design; Software design

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1. Introduction

Wireless fire alarm is a major application direction of modern science and technology. Especially, data fusion technology plays an indispensable role and advantage [1]. Based on this, researchers need to combine the practical application requirements of the system to reasonably determine the main application ideas of data fusion technology in it. Based on this, with the help of data fusion technology, the hardware and software parts are reasonably designed to make it more flexible and intelligent. Only in this way can more advanced technical support be provided for modern fire alarms to achieve timely discovery and rescue of fire situations [2].

2. Basic design idea of wireless fire alarm system supported by data fusion technology

Under normal circumstances, the occurrence of a fire can be divided into four stages: early stage, smoldering stage, flame heat release stage, and attenuation stage. In the early stage, the flame, smoke, gas, and heat released by combustion are usually relatively small. In the smoldering stage, a large amount of smoke will be generated, but the flame heat will not be very high [3]. In the flame exothermic stage, a large amount of heat will be released and radiated, and the temperature of the fire site will rise rapidly under open-flame conditions. In the attenuation stage, as the combustible material gradually burns out, the flame will gradually become smaller, and the released smoke and heat will gradually decrease. Based on this, when a fire occurs, the wireless alarm system should try to detect the fire situation before the flame exothermic stage and issue an alarm in a timely manner [4].

To achieve this goal, in this system design, researchers mainly use wireless sensors to collect various fire data and use a wireless network composed of sensor nodes and coordinator nodes to transmit fire data to the host computer in a timely manner. With the help of data fusion technology in the host computer, the fire data is fused and processed, and an image recognition function is added to meet the timely perception of the fire situation and timely alarm requirements [5].

3. Analysis of hardware design of wireless fire alarm system

3.1. Hardware design supported by sensors and wireless transmission

In this design of the wireless fire alarm system, the designer mainly designs the wireless sensor network hardware of the system based on the CC2530 chip of the ZigBee communication protocol, which integrates A/D conversion, MCU, and RF transceiver modules, etc., making it small enough and low power consumption, suitable for all kinds of wireless sensor network nodes [6]. The sensor and wireless sensor network unit are set as sensor nodes, and three analog numerical sensors are set on each node, including CO sensor, smoke sensor, and temperature sensor. The sensor data is converted by an A/D converter and then sent to the host computer through the wireless RF module composed of CC2530 chip.

3.2. Hardware design supported by coordinator and wireless transmission

In the wireless sensor network structure of the system, the designer only sets up a coordinator, whose main role is to be responsible for the establishment, maintenance, and control of wireless sensor network nodes and to collect monitoring data from various sensors [7]. Its wireless transmission support hardware mainly includes RS232 serial port, MUC, and wireless transceiver unit. The hardware module is connected to the host computer in a wired manner to meet its data transmission needs and the specific data format definition needs to be realized under the support of the corresponding program. Compared with the sensor node, the biggest difference of the hardware is the addition of a serial port module. **Figure 1** shows the basic schematic diagram of the serial circuit of the coordinator of the wireless fire alarm system:

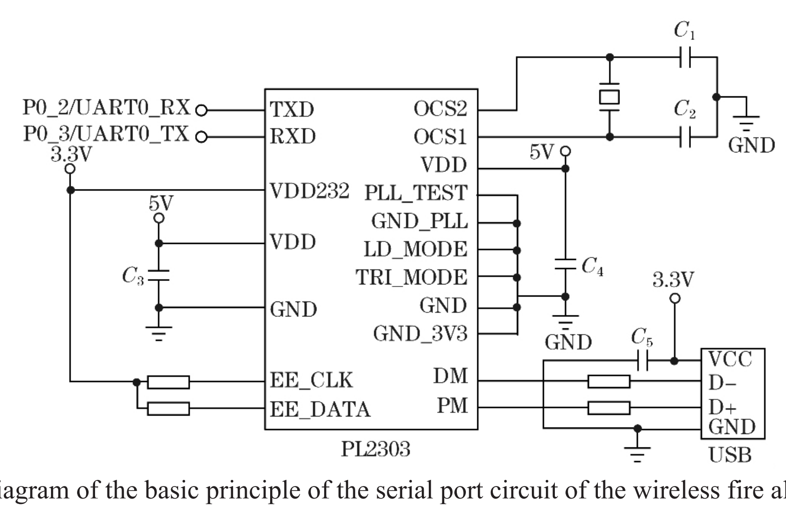

Figure 1. Schematic diagram of the basic principle of the serial port circuit of the wireless fire alarm system coordinator

4. Analysis of software design for wireless fire alarm system supported by data fusion technology

4.1. Algorithm design supported by data fusion technology

In terms of current data fusion technology for fire monitoring, the neural network algorithm is the most suitable supporting algorithm. This algorithm has a very strong nonlinear mapping capability, excellent adaptive and self-learning abilities, and good fault tolerance. This is a typical parallel processing algorithm. In practical applications, researchers can utilize this algorithm to build a perception-based classifier. Within a wireless fire alarm system, the classifier functions as a binary classifier that produces two possible outcomes: one representing valid alarm information and the other representing invalid alarm information. Based on this classifier, researchers can introduce a neural network algorithm supported by data fusion technology, using the monitoring information obtained from sensors as a basis to calculate fire alarm results in a timely and accurate manner through learning and training, thereby verifying the validity of fire alarm information [8].

There are also many forms of current neural network algorithms, among which the most representative algorithm model is the feedforward neural network algorithm. Based on this, in this system design, researchers have introduced a feedforward neural network algorithm with a hidden layer. It is a multilayer perceptron structure that can be used for nonlinear discrimination and its training algorithm is the particle swarm optimization algorithm. Considering that different types of sensors produce data within different ranges, and to prevent discrepancies in data size during actual computations, this algorithm standardizes sensor data with unknown minimum and maximum values using a Gaussian normalization algorithm [9]. The following is the algorithm formula for its normalization process:

$$z = \frac{x - \mu}{\sigma} \quad (1)$$

In this equation, z represents the standardized processing result of sensor monitoring data; μ represents the mean value of original sensor monitoring data; σ represents the variance of original sensor monitoring data. The standardized sensor monitoring data is used as input data for the neural network algorithm, ensuring that each connection within the connected hidden layers corresponds to a weight value (represented as here). The total value of each node in the hidden layer (represented as here) is used as the weighted sum of input values. The calculation formula is:

$$S_{i} = \sum_{j=1}^{n} w_j X_j + w_0 \quad (2)$$

In this equation, represents the total number of nodes; j represents the j-th node; represents the j-th input value; represents the initial weight value. Using the Sigmoid function as the activation function in neuron model calculation, with the support of this activation function, the neural network algorithm calculates the value in the hidden layer according to the following formula:

$$S_j = sigmoid(S_{i}) \quad (3)$$

For the parameters transmitted from the hidden layer to the output layer after processing, the neural network algorithm will continue to calculate them through a weighted sum approach. The calculation formula is as follows:

$$Y_{j} = \sum_{j=1}^{n} v_j S_j + v_0 \quad (4)$$

Based on this equation, represents the weighted sum of the output values; represents the total number of output parameters; *j* represents the jth parameter output in the output layer; represents the jth parameter value output; represents the starting output value. For the output layer, the neural networks algorithm mainly implements classification processing through the Softmax function, so that the sum of the output points after adding the values is 1.0, and the result of each output point is considered to be the basis for its content probability judgment. In this calculation mode, the output value of each output point can be expressed as:

$$Y_j = Soft\max(Y_j) \quad (5)$$

Based on the parameter values output by each output point, the neural network algorithm model can accurately determine the fire monitoring results and the probability of fire occurrence from various sensors on site. Typically, if the probability value is judged to be high, the model will use it as the fire alarm judgment result. In the practical application of data fusion technology based on neural network algorithms, the most critical process is its training. Therefore, in the specific design of the system, researchers need to make a reasonable choice of training algorithms. In the current wireless fire alarm system, the Particle Swarm Optimization (PSO) algorithm is a typical algorithm under global random optimization conditions for data fusion technology based on neural networks. Its basic principle is to use various individual components in the particle swarm to perform repeated iterative processing within the overall data space to find the optimal solution. In the process of calculation through the PSO algorithm, a series of virtual particles will be fully recorded and used as the optimal solution to the problem [10]. The neural network algorithm corresponding to each optimal solution represents a series of weights. With these weights, the neural network algorithm can make the calculated output value closest to the output value in the known training data, thus achieving scientific determination of the best weights. In each iteration, the neural network algorithm updates the speed and position of individual particles according to the following formulas:

$$v(t+1) = w \cdot v(t) + c_1 r_1 [p(t) - x(t)] + c_2 r_2 [g(t) - x(t) \quad (6)$$

$$x(t+1) = x(t) + v(t+1) \quad (7)$$

In these equations, *t* represents the number of iterations; *w* represents the coefficient of inertia; and represent the acceleration coefficient; and represent random numbers randomly distributed in the range of [0,1]; *g (t)* represents the optimal position of all particles at the current time; *v* and *x* represent the potential solution corresponding to the desired problem. In this algorithm, each particle can record its own optimal position (represented here by *p (t)*), and *g (t)* represents the optimal position of all particles at the current time. Based on the above algorithm process, after repeated iterations, the optimal weight under the conditions of the neural networks algorithm can be accurately calculated. According to the specific calculation results, it can be timely and accurately judged and decided whether to immediately fire alarm. The closer the calculated optimal weight is to 1, the greater the probability of actual fire occurrence, and the system can combine the display results in the image recognition module to issue a fire alarm in time.

4.2. Design of the system software image recognition module

In this designed system, the image recognition program is only used to provide assistance for the fire judgment of the wireless sensor network system. In the specific design, the researchers use the color recognition model based on the RGB (red, green, and blue) flame color to obtain the color component and combine the color saturation in the HIS (hue, brightness, saturation) model to make a reasonable setting of the R component threshold. Under normal circumstances, when the R component is between 115 and 135 and the S component is between 55 and 65, if the recognized color meets the following formula, the recognized color is considered to be the flame color:

$$R > R_T \tag{8}$$

$$R \geq G > B \tag{9}$$

$$S \geq (255 - R) \cdot S_T / R_T \tag{10}$$

From these equations, represents the red component threshold identified by the system, and represents the saturation threshold identified by the system. By designing the image recognition module in the system reasonably based on the above conditions, timely and accurate identification of flame features can be achieved, and statistics and display of recognition results can be properly done, thus providing support and assistance for fire warning judgments based on neural network algorithms.

4.3. System software design for the host computer program

In this system, the main function of the host computer is to receive monitoring data from various sensors, store the data in a database, and utilize data fusion algorithms and image recognition programs to make timely and accurate judgments on detected fire situations, thereby ensuring the prompt transmission of fire alarm information. To achieve this goal, in this design, researchers mainly designed the following program for the host computer through C# programming language. After starting, the neural network algorithm module and image recognition module will start simultaneously.

After the neural network algorithm module starts, the system will detect the serial port and turn on the serial port receiving function to determine if the serial port data is correct. If it is correct, the next step will be executed; if it is incorrect, the serial port reception will continue until the serial port data is confirmed to be correct. The correct serial port data needs to be processed by the data fusion algorithm and based on the calculation results, it will be judged whether it meets the alarm criteria. If it meets the criteria, the system will immediately send an alarm; if not, it will return to the data fusion algorithm for further calculation.

After the image recognition module starts, the system will judge whether an image has been received. If an image is received, the next processing step will continue; if no image is received, the image sensor will continue to be turned on until an image is received. For the received image, after processing and recognition by the module, it will judge whether the flame color is detected. If the flame color is detected, the system will immediately send an alarm; if no flame color is detected, it will return to the image processing step.

5. Simulation analysis of the wireless fire alarm system supported by data fusion technology

For the wireless fire alarm system designed based on data fusion technology in this study, to verify its application effect, researchers simulated it with fire data through virtual simulation. During the specific simulation, researchers introduced 100 sets of normalized data and performed fusion calculations on them using the neural network algorithm supported by the system's data fusion technology. Analysis of the calculation results showed that the error could be controlled to about 3%, indicating that the accuracy of the data fusion calculation results introduced into the system is very high. **Table 1** shows the simulation results of the wireless fire alarm system supported by data fusion technology in this study:

Table 1. Simulation results of the wireless fire alarm system supported by data fusion technology in this study

Serial number	CO	Temperature	Smoke	Calculation results	Data results
1	0.750	0.900	0.220	0.943	0.960
2	0.930	0.880	0.200	0.920	0.930
3	0.780	0.380	0.310	0.765	0.780
4	0.680	0.320	0.510	0.653	0.680
5	0.350	0.210	0.300	0.360	0.350

At the same time, considering that there is a direct correlation between the accuracy of neural network algorithm calculation results and the quantity and precision of its training data, researchers need to introduce more high-precision training data to train the neural network algorithm model in subsequent practical applications. This can further enhance the accuracy of the neural network algorithm model's calculation results, fully leverage the advantages of data fusion technology, and make more timely and precise judgments on fire situations. Thus, it provides strong support for the timely detection, alarm, and suppression of fires.

6. Conclusion

In summary, data fusion technology is a critical technology in the design of modern wireless fire alarm systems, assisting in determining fire situations and making timely alarm decisions. Based on this, researchers should fully recognize the application advantages of data fusion technology and clarify its application methods. By considering the requirements of fire monitoring and fire alarm in the practical application of wireless fire alarm systems, data fusion technology should be reasonably introduced to establish corresponding algorithm models, enabling reasonable analysis and processing of fire monitoring data and providing scientific decision-making for whether to immediately execute the fire alarm procedure. Simultaneously, with the support of image recognition technology, further assistance should be provided for fire judgment and fire alarm in the system to ensure the timeliness and accuracy of fire alarms.

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Disclosure statement

The author declares no conflict of interest.

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