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New cycle temperature measurement and control system in Daqu fermentation room

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Abstract

In order to solve the problems of uneven fermentation of the rhizopus brick, multiple temperature measurement points, complicated temperature structure and unsuitable fine-tuning and control of the temperature system in the traditional Daqu fermentation room, a dual neural network control algorithm and internal circulation pipeline structure were proposed to achieve real-time temperature measurement and control of the Daqu fermentation room The internal air circulation in the room is also introduced. After experimental testing, the system works stably, and can accurately measure and control the ambient temperature of the Daqu fermentation room during the fermentation process of the rhizopus brick, so that the temperature in each area of the Daqu fermentation room can be kept uniform.

Keywords

Kingview; memory sharing; EtherNet/IP communication; double neural network; inner loop.

1. Introduction

The fermentation of rhizopus brick in Daqu fermentation room influences the quality of liquor directly and the fermentation depends mainly on the rhizopus brick itself and environmental microorganisms, whose growth and metabolism are mainly affected by the ambient condition in Daqu fermentation room. The main environment needed for fermentation of microorganisms are low oxygen, high humidity and high temperature, of which changing in temperature is vital to fermentation of rhizopus brick. [1-2].

Therefore, the effective control of Daqu fermentation room temperature is of great significance in improving the quality of liquor. At present the research and development of intelligent Daqu fermentation room in China is still in the engineer testing stage and some result has been achieved in temperature control method of Daqu fermentation room. The technology of temperature and humidity wireless control by automatic window open and close, proposed by Zhao Dianchen etc.[3], controls temperature in Daqu fermentation room by controlling the range of the window opening. However, opening window will cause interchange of air in and out of Daqu fermentation room, which will lower the humidity and concentration of carbon dioxide and will affect fermentation of rhizopus brick. In Temperature Measuring Points Optimization and Modeling Research Based on Fuzzy C-Means Clustering Algorithm proposed by Huang Juan etc.[4], optimizing points are selected by means clustering and therefore reduced. But this method is not suitable for environment of high density and multivariable like Daqu fermentation room. In Research on control system of greenhouse temperature and humidity based on fuzzy neural network proposed by Wu Xiaoqiang etc.[5], Intelligent Temperature Control of Beer Fermentation System proposed by Chen Xiaochun[6], Research on Vacuum Chamber Temperature Control Based on Fuzzy Adaptive PID proposed by Zhang Shenyu etc.[7], problem of too few temperature measuring points are solved, which is not suitable for temperature control of Daqu fermentation room for its multi-input.

Based on current search, in order to avoid above problems of air interaction inside and outside Daqu fermentation room, too many temperature measuring points, too large data volume and to realize real-time temperature control in Daqu fermentation room highly effectively and accurately, a new type of temperature measurement and control system in Daqu fermentation room is intended to be developed. The overall structure of intelligent Daqu fermentation room is shown in Figure 1. The focus is on improving the hardware structure of temperature controlling system and temperature control algorithm. In order to make temperature inside Daqu fermentation room more uniform, internal circulation pipeline structure and Cascaded neural network control are innovatively designed.

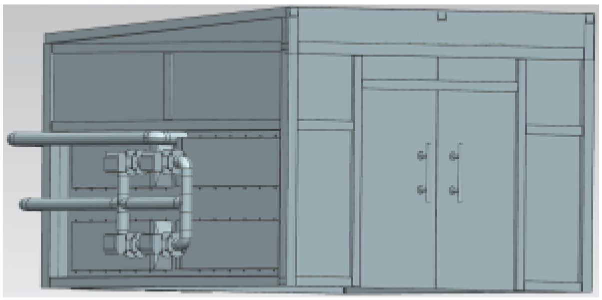
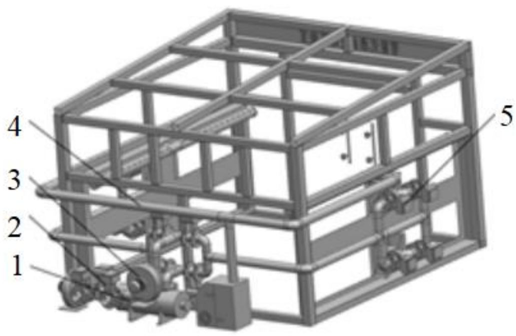


Figure 1 Intelligent Daqu fermentation room

2. System composition

As there is a large quantity of high-temperature anaerobe in rhizopus brick, temperature, humidity and concentration or carbon dioxide should be higher than outside at microorganism fermentation. Opening window for ventilation and traditional Daqu fermentation room temperature control will both expose air inside Daqu fermentation room to outside, which will cause humidity and carbon dioxide concentration in Daqu fermentation room to decrease and is not good for fermentation of microorganisms.

In order to interact air inside Daqu fermentation room with outside while controlling temperature, internal circulation pipe structure is used. This structure can circulate air inside Daqu fermentation room in the circulating pipe, not exposing to outside air while controlling temperature, thus reducing the loss of humidity and carbon dioxide. The inner circulation pipe structure is shown in Figure 2(a).



1. Heater 2.Wind direction switch butterfly valve 3. Fan 4. Air pipe 5. Tuyere opening butterfly valve

(a)Intelligent Daqu fermentation room structure

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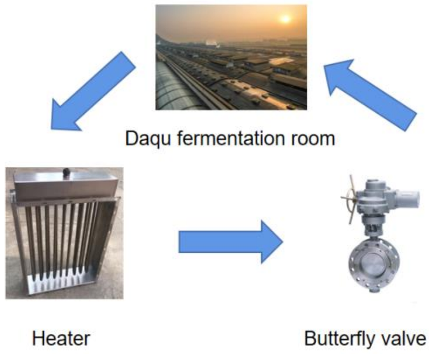

(b)Circulatory system in Daqu fermentation room

Figure 2 Intelligent Daqu fermentation room structure and internal circulation system

The internal circulation system controls temperature by controlling air pipes and sucks air in the upper left, lower left, upper right and lower right of Daqu fermentation room by changing the flow rate of tuyere opening butterfly valve in different directions and the status of wind direction switch butterfly valve. Air sucked flows through internal circulation pipe and heat source in the heater and then reenter[Daqu fermentation room from pipes in the 4 directions. The circulation model is shown in Figure 2(b). This system can isolate air inside Daqu fermentation room from outside, preventing loss of humidity and carbon dioxide.

The frame diagram of internal temperature measurement system structure is shown in Figure 3. When the system is running the wireless module receives analog signals from each sensor and convert it into digital signals, which is received by wireless router before being transmitted to the host computer for analysis. Control command is sent to PLC according to results received. The analog control module and the digital output module control the output frequency of the converter and thus control the changes of temperature parameters during fermentation of rhizopus brick.

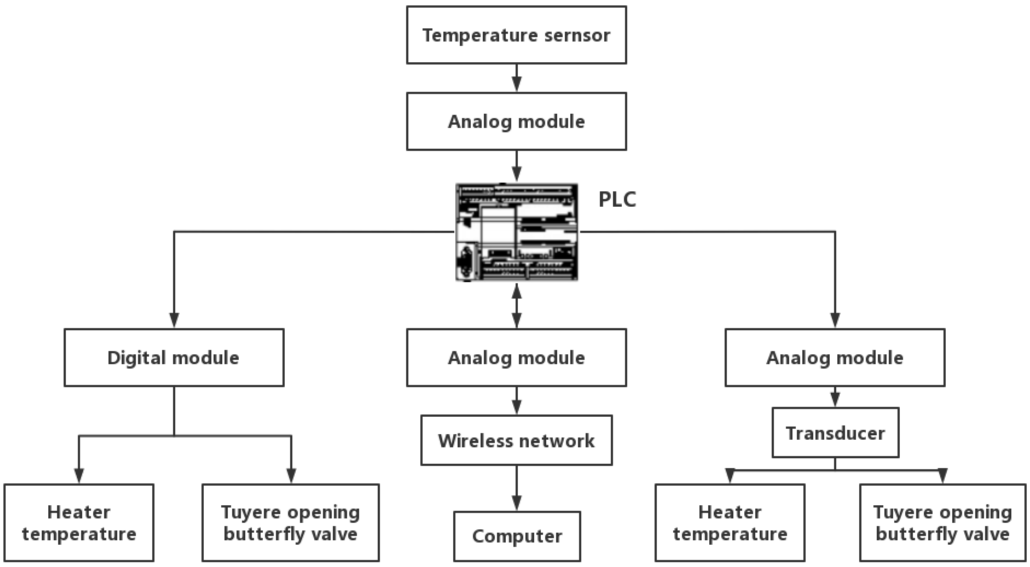

Figure 3 Hardware structure frame of intelligent Daqu fermentation room measurement and control system

Software frame diagram is shown in Figure 4. Communication between the host computer software and PLC is realized by EtherNet/IP protocol. PLC uses Ethernet communication module to transmit the data collected by sensors to the host computer by way of Ethernet. The data is received, dealt, enquired and displayed on the host computer. VisualStudio calls data in

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Kingview by DDE share, does Cascaded neural network calculation and sends control parameters back to local address, waiting for Kingview to download.

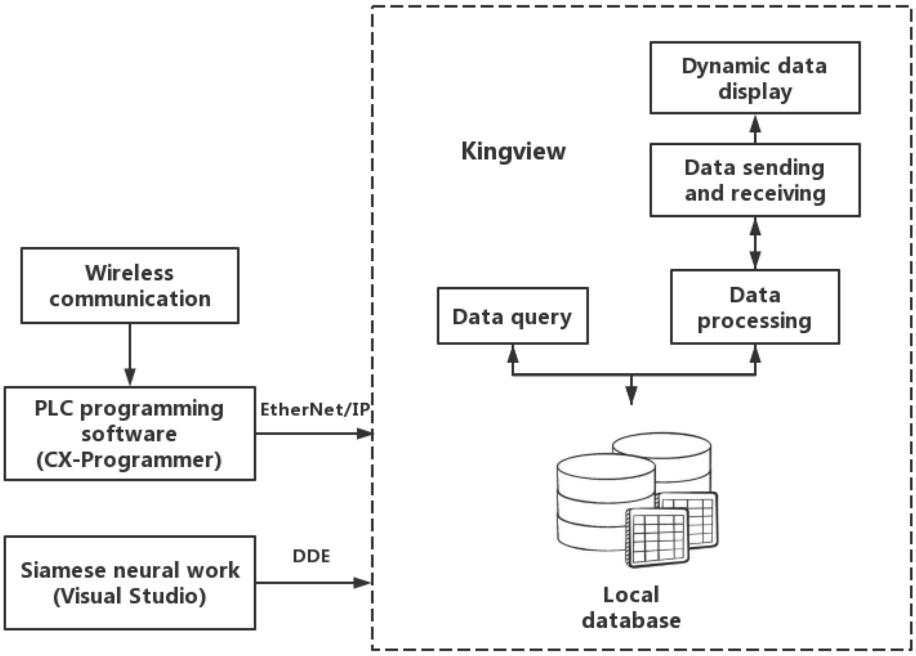

Figure 4 Software system

3. Cascaded neural network control algorithm

When collecting and controlling temperature of Daqu fermentation room following problems exists: space in Daqu fermentation room is large and temperature between different positions, especially upper and lower layers, have significant differences; temperature sensors cannot be placed at suitable positions due to large number of rhizopus brick and frame stacked in Daqu fermentation room; too few collecting points will lead to poor reflection of actual temperature in the room while too many collecting points will lead to inconspicuousness of feature data; collecting points are easily affected by temperature of rhizopus brick itself if placed close one.

As is shown in Figure 5, temperature control method based on Cascaded neural network is used in order to solve above problems. The core algorithm is consisted of clustering algorithm and temperature control algorithm. While clustering algorithm receives temperature data from all collecting points and cluster to K feature temperature through non-linear mapping; temperature control algorithm take clustered feature temperature as inputs, output 8 control parameters to control flow rate and heating power of tuyere opening butterfly valve and in turn to adjust temperature of the room.

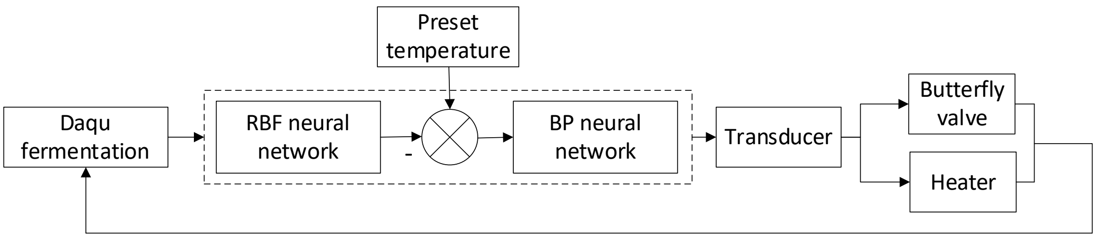

Figure 5 Control flow of temperature system in Daqu fermentation room

Due to strong non-linear fitting ability of RBF neural network, it can map non-linear relation of any complication. Furthermore, its learning rules are simple, with advantage of very strong robustness, memory ability, non-linear mapping ability and strong self-learning ability and so forth, it is selected as clustering network. Compared to traditional PID control, BP neural network has some intelligence and timeliness, and it can adjust temperature control system in line with temperature change in Daqu fermentation room.[8-11]

The 1-5 layers of Cascaded neural network algorithm are input layer, RBF hidden layer, middle layer, BP hidden layer and BP output layer. Network learning method, used to adjust and optimize output signal of Cascaded neural network, can give the algorithm abilities of logic judgment and self-optimization, which can modify output signal by gradient descent method [12-14]. The center, width, adjusted weight parameters and error correction are all adjusted to optimum through learning. The iterative calculation are as follows:

$$w_{kj}(t) = w_{kj}(t-1) - \eta \frac{\partial E}{\partial w_{kj}(t-1)} + \alpha[\partial w_{kj}(t-1) - \partial w_{kj}(t-2)], \quad (1)$$

$$c_{kj}(t) = c_{kj}(t-1) - \eta \frac{\partial E}{\partial c_{kj}(t-1)} + \alpha[\partial c_{kj}(t-1) - \partial c_{kj}(t-2)], \quad (2)$$

$$d_{kj}(t) = d_{kj}(t-1) - \eta \frac{\partial E}{\partial d_{kj}(t-1)} + \alpha[\partial d_{kj}(t-1) - \partial d_{kj}(t-2)], \quad (3)$$

$$e_j(t) = (\sum_{k=1}^{q} v_{kj} \cdot d_k) b_j (1 - b_j), \quad (4)$$

In the form:

$d_{kj}(t)$--Width;

$c_{kj}(t)$--Central component;

η——Learning factor.

the error function is:

$$E = \frac{1}{2} \sum_{l=1}^{N} \sum_{k=1}^{q} (y_{lk} - O_{lk})^2, \quad (5)$$

$$d_k = (O_k - y_k) y_k (1 - y_k), \quad (6)$$

In the form:

y_{lk}——RBF Network output value;

O_{lk}——Expected intermediate output value;

y_k——Network output value;

O_k——Expected output value.

output of the RBF hidden layer is:

$$z_j = \exp(-\left\|\frac{x - c_j}{d_j}\right\|), \quad (7)$$

In the form:

c_j——Center vector of hidden layer;

x——Input temperature, ℃;

d_j——Input temperature vector.

The output of the middle tier:

$$y_k = \sum_{j=1}^{p} w_{kj} z_j, \quad (8)$$

In the form:

w_{kj}——The regulatory weight of the bond between the k neuron in the output layer and the j neuron in the hidden layer.

The output of the BP hidden layer is:

$$b_j = \frac{1}{1 + \exp(-\sum_{i=1}^{n} w_{ji} \cdot x_i + \theta_j)}, \quad (9)$$

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In the form：

θ_j——Threshold value；

w_{ji}——Weight.

4. Simulation and analysis

4.1. Simulation analysis

As shown in Figure 6, Daqu fermentation room is simplified to a 4m*4m*4m model using solidworks. Based on this model, the influence of butterfly valve flow rate and heating temperature on the temperature change of Daqu fermentation room is simulated and analyzed in ANSYS. The initial temperature of Daqu fermentation room is set to 20, the wall is set to fixed thermal conductivity in order to simulate the heating mode of internal circulation of air intake on one side while on the other side air is heated at constant temperature and while been taken in.

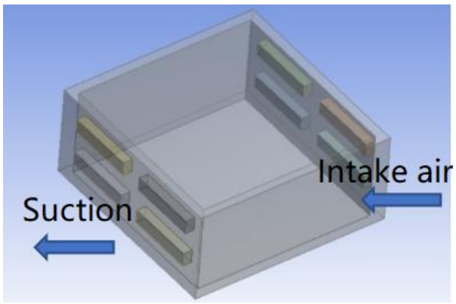
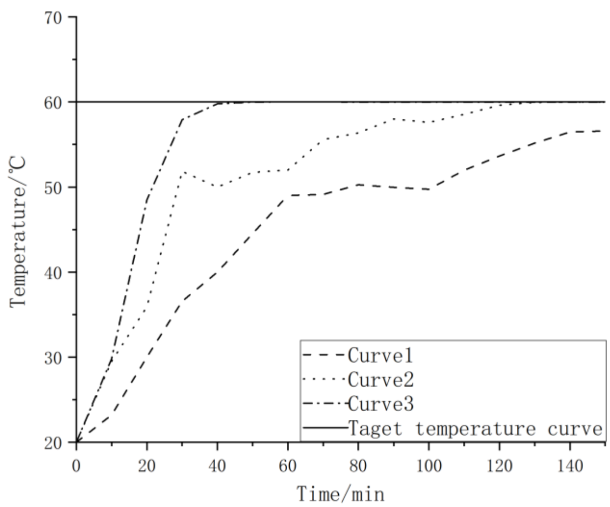


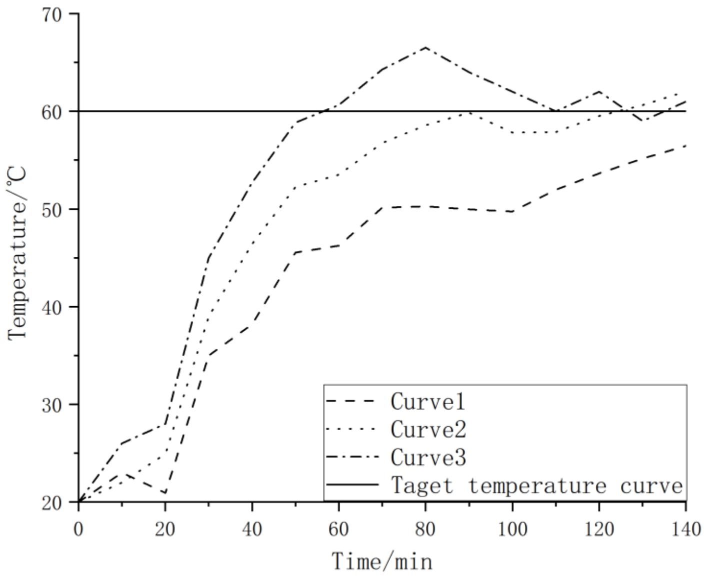
Figure 6 Simplified model of Daqu fermentation room

As can been seen from Figure 7 that the higher inlet air temperature and faster flow velocity are, the fast temperature will arise in Daqu fermentation room. Thus it indicates that when Daqu fermentation room needs heating or cooling hot or cold air with high flow rate can be sent in, and that when in the stage of constant temperature, in order to uniform temperature of Daqu fermentation room, air with low velocity and similar temperature is need for fine-tune.



The curve 1 to 3 is 1, 2, 3 m/s respectively

(a)Temperature variation curve of Daqu fermentation room center



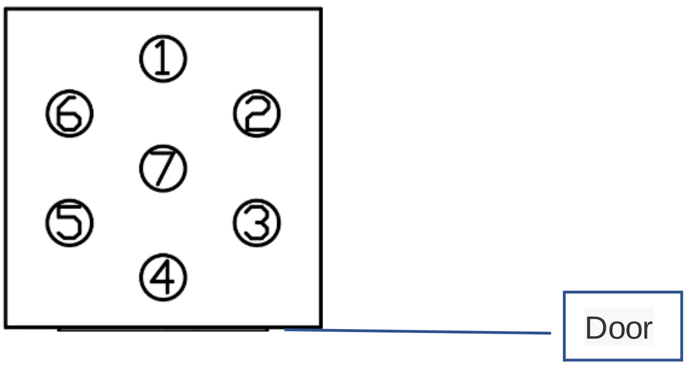
The curve 1 to 3 is 50, 60, 70 ℃respectively

(b)Temperature variation curve of Daqu fermentation room center

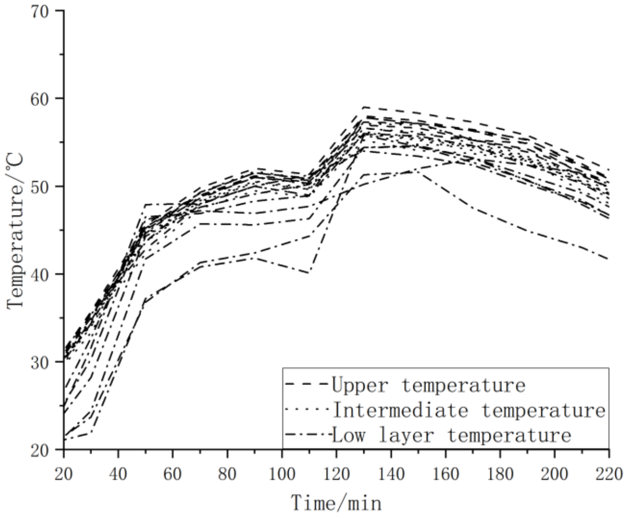
Figure 7 Comparison of the central temperature of the curvature chamber at different flow rates and temperatures

4.2. Optimization analysis

In order to express the temperature field structure of Daqu fermentation room, temperature control experiment of Daqu fermentation room is carried out. 21 temperature sensors are distributted among upper, middle and lower panel of Daqu fermentation room evenly. Distribution of each layer is shown in Figure 8(a). In order to facilitate distribution of sensors and reduce the interference caused by the temperature of rhizopus brick, the experiment is carried out in an empty Daqu fermentation room and the data of temperature sensors is recorded every 10 min.



(a)Plane distribution of temperature collection points



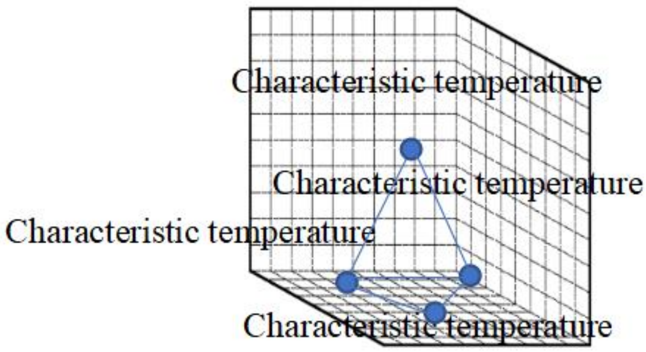
(b)Comparison of temperature data at different acquisition points

Figure 8 Control flow of temperature system in Daqu fermentation room

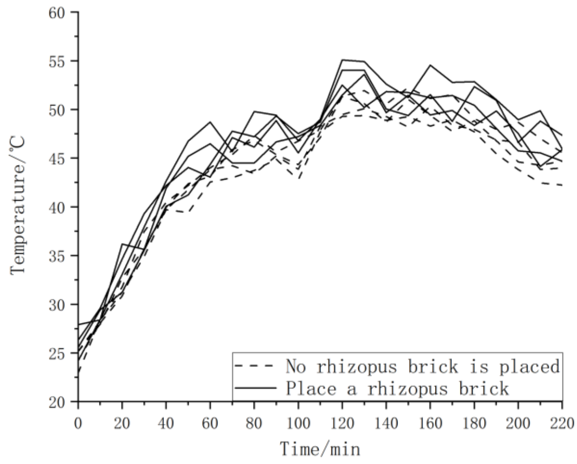
It can be seen from Figure 8(b) that temperature in Daqu fermentation room tends to be stable in the top while fluctuates in the bottom. Temperature is basically stable in the top and middle layers but differs much in the bottom layer.

With above reasons taken in to consideration, data of sensor 4 form upper center point, sensor 5 from lower layer, sensor 6 from lower layer and sensor 7 from lower are chosen for feature data, which are trained using RBF network. The feature sensors, as their distribution shown in Figure 9(a), form a tetrahedral structure, which can express temperature condition of the whole room.

In order to show the influence of temperature from fermentation of rhizopus brick on collecting temperature, 4 sensors are place on frame with and without rhizopus brick. Experimental data is recorded every 5 min and the result is shown in Figure 9(b). Collected temperature of frame with rhizopus brick is slightly higher that those without rhizopus brick.



(a)Characteristic temperature distribution point



(b)Temperature error curve of sensor

Figure 9 Characteristic temperature point distribution and sensor temperature error curve

A total of 1500 sets of measured temperature data are used as experimental data, of which 1200 sets are randomly chosen to set to training set, 300 sets are set to testing set for RBF neural network training and 225 sets of rule data, which are trained to Cascaded neural network with 17 inputs and 4 outputs. Training method of weight parameters is gradient descent method and the weight parameters are adjusted to the optimal value by learning, and the number of network layers set to 4, with number of nodes be 34, 15, 17, and 16. As input value of this system is any value in the range of -20-20 and output value is non-negative, sigmoid type transfer function is used as transfer function [15-17]. The form of the function is:

$$g(x) = \frac{1}{2}[1 + \tanh(x)] = \frac{e^x}{e^x + e^{-x}} \quad (10)$$

RBF network control algorithm is used to verify the clustering effect of Cascaded neural network. 9 sets of temperature are used for clustering test. The result is shown in Figure 10. The error between two curves is less than 1% and the similarity between the network output feature data and the real feature data is more than 99%.

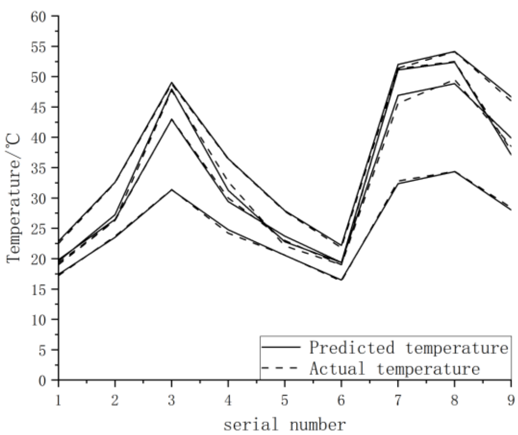


Figure 10 Comparison between the output characteristic data of RBF network and the real features of characteristic data collection points

It can be seen from Table 1 that response time of temperature clustering of RBF neural network is short. The accuracy of RBF neural network is 99%, which is much higher than drift algorithm and particle filter algorithm.

Table 1 Algorithm comparison

Arithmetic	Response time/s	Precision/%
Mean algorithm	25	33
Particle filter algorithm	410.7	60
PRB clustering algorithm	200	99

4.3. Result analysis

Control effect is test after using new inner circulation control system in Daqu fermentation room. Temperature in Daqu fermentation room at test is 25, target temperature is 55, data is collected every 10 min. The curve drawn from data collected is shown in Figure 11, of which actual temperature is temperature collected by sensors. Target temperature is reached at around 60 min and can be stabilized ±3 ℃ for long time for a long time.

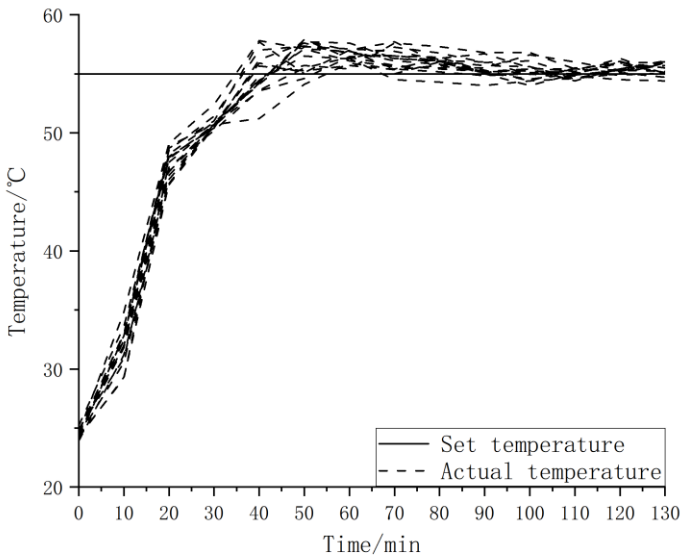


Figure 11 Effect of temperature measurement and control in Daqu fermentation room

5. Conclusion

A new type of temperature measurement and control system for internal circulation in Daqu fermentation room is designed, the software and hardware design and testing platform of the measurement and control system based on internal loop structure and Cascaded neural network algorithm are completed and verified by ANSYS simulation and test methods. The result shows that new internal circulation temperature control system of Daqu fermentation room has good stability and anti-interference ability. With a smooth temperature curve, target temperature is reached at around 70 min, stablizing at around for long time, which meets the requirement temperature control requirement of fermentation of Daqu fermentation room. The experiment mainly studies the temperature around the fermentation rhizopus brick, but does not consider the boundary temperature between the outlet of the internal circulation pipe and the door frame. The next step is to reduce the heat loss by improving the material properties and covering the film, so as to make the temperature in the Daqu fermentation room more uniform and stable.

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