BP neural network PID temperature control of beer fermentation tank

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Abstract. The temperature control of beer fermentation has many features, such as great inertia, time delay, non-linear, time-variant. The effect of traditional PID is poor. In order to improve control effect, this paper proposes a BP neural network PID control algorithm. By add momentum to reduces vibration time and accelerates the convergence of the neural network. Adjusts PID parameters online by optimized BP neural network, it solves the problems of slow response and large overshoot of traditional PID control method. And control the temperature of beer fermentation tank by PID controller. Finally, the simulation that using MATLAB for beer fermentation tank proved this controller has real-time performance, small overshoot, robustness, rapid response speed and other advantages.

1. Introduction

Beer is one of the oldest drinks in human history. The production of beer mainly includes: malting, mashing, fermentation and other steps. Fermentation is one of the most complex steps, includes lots of biological and chemical reactions, takes longest times, demands higher of temperature controlling [1]. It is the most key step which could determine the quality of beer. The beer fermentation process has the features of large time delay, great inertia, time-varying , non-linearity which make it difficult to control [2].

Recently, many domestic and foreign researchers combine traditional PID with other control algorithms. It has simple structure, good stability and high reliability in Traditional PID control. By combined with other algorithms can modify the PID parameters online, which can improve control effect significantly. For example, fuzzy PID control strategy. Although it can improve control effect, it still a range estimation and fuzzy subsets, membership function, initial PID parameters also require experience to estimate, which make the possibility of application greatly reduced [3]. Neural network has good learning ability, nonlinear processing capability, good robust stability [4]. Use neural network to modify PID parameters online can solve the problem of beer fermentation tank temperature control. However, restricted by the search algorithm, the neural network is usually to fall into the local
minimum which impact control effect [5]. Therefore, this paper presents additional momentum terms algorithm. Add a minimum momentum term which make neural network to search global minimum fast, when neural network needs to modify weight. Thus, the control deviation caused by local misdirection can be avoided. The simulation results show that improved neural network PID control strategy can satisfy requirements of beer fermentation temperature control.

2. Principle of beer fermentation

Beer is fermented in a fermentation tank. It is divided into two parts, including primary and secondary fermentation. Primary fermentation is a natural warming process, secondary fermentation requires to lower the temperature of fermentation tank which based on technical requirement [6]. As shown in the figure 1 is ideal temperature curve.

![Temperature curve](image1.png)

**Figure 1.** Fermentation temperature curve

The entire fermentation process lasts nearly 20 days. With the fermentation process through, different stages require different temperature. If the temperature of fermentation tank can be controlled within the range of 0.5°C of given temperature, the quality of beer will be good.

The structure of a beer fermentation tank is cylindrical at the top and tapered tapered at the bottom. As shown in the figure 2 is the structure of fermentation tank. Beer fermentation is a complex biological and chemical process, which will release lots of heat, so we need to control tank temperature. There are three cooling devices and three temperature measuring devices at the upper, middle and lower parts in beer fermentation tank [7].

![Structure of fermentation tank](image2.png)

**Figure 2.** The structure of a beer fermentation tank
3. Control method research

3.1. BP neural network PID control method

There are many features such as large time-delay, great inertia in the process of beer fermentation [8]. So traditional PID algorithm does not work well. Neural network has the function of autonomous learning, combined with PID can combine this advantages. The structure is shown in the figure 3.

![Figure 3. The structure of NNPID](image)

The controller is composed of traditional PID and neural network. PID controls temperature directly. Neural network adjusts PID parameters according to the system conditions, which can optimize control effect [9].

3.2. Improved BP neutral network PID algorithm

The structure of BP neutral network is shown in the figure 4.

![Figure 4. The structure of BPNN](image)

The input of input layer is

\[ y_j = \left( x_j \right) \]

The input of hidden layer is

\[ O_j^{(1)} = x(j) \quad (j = 1,...,M) \]
\[ net_i^{(3)}(k) = \sum_j w_{ij}^{(2)} O_j^{(2)} \]  
\[ O_j^{(2)}(k) = f(net_j^{(2)}(k)) \quad (i = 1 \ldots Q) \]  

\( w_{ij}^{(2)} \) is weighting coefficient; (1), (2), (3) is the input hidden and output layer [10].

Hidden layer uses Sigmoid as its activation function.

\[ f(x) = \tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} . \]  

The input of output layer is

\[ net_i^{(3)}(k) = \sum_{i=0}^{Q} w_{li}^{(3)} O_i^{(2)}(k) \]  

The output of output layer is

\[ O_i^{(3)}(k) = g(net_i^{(3)}(k))(l = 1, 2, 3) \]  

\[ O_1^{(3)}(k) = k_p \]  
\[ O_2^{(3)}(k) = k_i \]  
\[ O_3^{(3)}(k) = k_d \]  

Use non-negative Sigmoid function as output layer activation function.

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

Indicator function is

\[ E(k) = \frac{1}{2} (r\text{ink}(k) - y\text{out}(k))^2 \]  

BP neural network adjusts weight by gradient descent method searching in the negative gradient direction of \( E(k) \). However, sometime the result is the local minimum, which will lead the parameters are not optimal. So in this paper, a momentum term is added to make sure that network can search global minimum rapidly.

\[ \Delta w_{ij}^{(3)}(k) = -\eta \frac{\partial E(k)}{\partial w_{ij}^{(3)}} + \alpha \Delta w_{ij}^{(3)}(k-1) \]  

\( \alpha \) is momentum coefficient, range of \((0, 1)\). \( \eta \) is learning rate. Add a momentum term will reduces the sensitivity of network to local details, which will reduce the risk of network falling into local minimum.

\[ \frac{\partial E(k)}{\partial w_{ij}^{(3)}} = \frac{\partial E(k)}{\partial y(k)} \cdot \frac{\partial y(k)}{\partial u(k)} \cdot \frac{\partial u(k)}{\partial O_i^{(3)}(k)} \cdot \frac{\partial O_i^{(3)}(k)}{\partial net_i^{(3)}(k)} \cdot \frac{\partial net_i^{(3)}(k)}{\partial w_{ij}^{(3)}} \]
Replace $\frac{\partial y(k)}{\partial u(k)}$ with $\text{sgn}\left(\frac{\partial y(k)}{\partial u(k)}\right)$,

\[
\frac{\partial u(k)}{\partial O_{1}^{(3)}(k)} = \text{error}(k) - \text{error}(k-1) \tag{14}
\]

\[
\frac{\partial u(k)}{\partial O_{2}^{(3)}(k)} = \text{error}(k) \tag{15}
\]

\[
\frac{\partial u(k)}{\partial O_{3}^{(3)}(k)} = \text{error}(k) - 2\text{error}(k-1) + \text{error}(k-2) \tag{16}
\]

The output layer weight algorithm is

\[
\Delta w_{li}^{(3)}(k) = \alpha \Delta w_{li}^{(3)}(k-1) + \eta \delta_{i}^{(3)}O_{i}^{(2)}(k) \tag{17}
\]

\[
\delta_{i}^{(3)} = \text{error}(k) \text{sgn}\left(\frac{\partial y(k)}{\partial u(k)}\right) \frac{\partial u(k)}{\partial O_{i}^{(3)}(k)} g'(net_{i}^{(3)}(k)) (l = 1, 2, 3) \tag{18}
\]

The hidden layer algorithm is

\[
\Delta w_{li}^{(2)}(k) = \alpha \Delta w_{li}^{(2)}(k-1) + \eta \delta_{i}^{(2)}O_{i}^{(1)}(k) \tag{19}
\]

\[
\delta_{i}^{2} = f'(net_{i}^{(2)}(k)) \sum_{l=1}^{3} \delta_{i}^{(3)}w_{li}^{(3)}(k) (i = 1, 2, 3) \tag{20}
\]

and $g'(\bullet) = g(x)(1-g(x))$, $f'(\bullet) = (1 - f^2(x)) / 2$.

4. Simulation analysis

This simulation uses small beer fermentation tanks, based on data and heat exchange equation get the mathematical model.

\[
G(s) = \frac{\theta(s)}{Q(s)} = \frac{-1.022e^{125}}{570s^2 + 48s + 1}
\]

$\theta(s)$ is temperature of beer fermentation tank. $Q(s)$ is variable refrigerant flow. The input of PID controller is ideal temperature and output is the reality temperature of fermentation tank. The number of hidden layer neurons is 5. Input of network is error between ideal temperature and reality temperature. Output are parameters of PID, $K_p$, $K_i$ and $K_d$. Use MATLAB for simulation.

The running time was 1000ms, disturbance was added at 600ms, and the target amplitude was 1. The simulation aims to traditional PID and BP neural network. The results of simulation is shown in the figure 5.
Figure 5. The result of simulation

As we can see in the figure 5, the overshoot of traditional PID is 1.2, peak time is 120ms, but neural network has no overshoot, and peak time is 150ms. After adding disturbance at 600ms, the overshoot of traditional PID appear again, and the overshoot is 1.15, the time to restore stability is 120ms. Neural network PID still has no overshoot, and the time to restore stability is 80ms. The simulation result proves that compare with traditional PID that BP neural network PID have no overshoot. BP neural network PID static performance is better. When add disturbance, BP neural network PID response faster, has better dynamic performance. The features of nonlinear, time-varying, great time delay in the process of beer fermentation were solved.

5. Conclusion

Aim to the of large overshoot, poor real-time performance, slow response in the temperature control of beer fermentation. This paper presented a control strategy based on neural network PID. As the fermentation process progresses, network adjusts the PID parameters by modifying the weight to meet the requirement of temperature control. By building a mathematical model and simulate with MATLAB, proved that the algorithm has the advantages of strong real-time, small overshoot, good robustness and so on, which greatly improved system performance.

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