Temperature Control System Based on Parameters-self-tuning Furry-PID for the Tank of Coffee Fermentation

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Abstract

Aiming at coffee fermentation tank's temperature possessing the characteristics of great inertia, pure time delay, difficulty in controlling time-varying in coffee wet processing, this control system applies parameters-self-tuning Furry-PID control algorithm to control the temperature. Through establishing mathematical model, simulation by MATLAB and practical application, the results show that compared to traditional PID control, parameters-self-tuning Furry-PID control possesses the characteristic of small overshoot, short period of oscillation, high precision and strong anti-jamming capability, ensuring the precious control of fermentation tank's temperature.

Keywords

Furry-PID control; Parameters-self-tuning; Temperature control; Coffee wet processing.

1. Introduction

Fermentation treatment is a significant procedure in coffee wet processing, which is one of the main causes of influencing coffee quality [Ruirui *et al.*, 2012]. The pectin mainly composed of sugar and plant fiber is very slimy on the surface of peeling coffee bean. Fermentation process is that pectin is hydrolyzed and degraded by enzymatic action in appropriate temperature. The control of fermentation tank's temperature is a significant component in coffee fermentation treatment. The precision of control directly determines the success of fermentation. However, because temperature possesses the characteristics of great inertia, pure time delay, difficulty in controlling time-varying, and enzyme is affected by temperature in coffee fermentation treatment, control is of difficulty. Traditional PID control no longer adapts to this Control object. According to wet processing and the feature of coffee in different batches, the parameters-self-tuning Furry-PID control combining fuzzy control and PID control is applied in controlling fermentation tank's temperature, achieving the purposes of tuning parameters online, obtaining good fermentation result and producing coffee of high quality.

2. The components of fermentation tank's temperature control system in coffee wet processing

The fermentation tank's temperature control system is composed of upper computer, data acquisition and controller, PH value acquisition, stirring control, temperature acquisition, door control, hot water circulation system and fermentation tank as shown in Figure 1. The fermentation temperature in tank is not constant during fermentation process and is determined by the ripeness of the coffee bean, elapsed fermentation time and PH value [Lizhen *et al.*, 2012].

2.1 Control parameter and temperature measurement component

According to processing requirement, the temperature departures of coffee bean is ±1℃. The temperature in fermentation tank is cooled by stirring with door opening. There are three levels of door opening size, 1/3, 1/2 and all. The temperature is heated by filling hot water. Therefore, the temperature of hot water and outdoor are considered as controlled parameter. During the control process, regulation valve can be utilized to control the flow of hot water. The integrative temperature transmitter using PT-100 as the sensor is applied as the temperature measurement component, which is composed of PT-100 and transmitter. PT-100 is fixed on temperature measuring point (the temperature of hot water, outdoor and coffee bean). The temperature data are sent to data acquisition and control system by the RS-485 bus of transmitter.

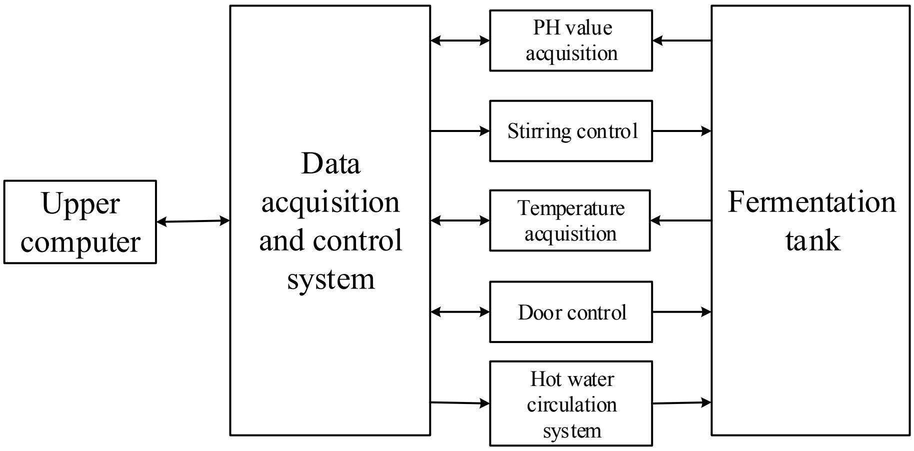

Fig1 Fermentation system composition block diagram

2.2 The design of data acquisition and control system

The structure of Furry-PID control system is simple, without special requirements of hardware, and the software control algorithm is rapid, only requiring simple table-referring in application. The hardware structure of the system is shown in Figure 2. The system is composed of upper computer, PT-100 temperature sensor combined with transmitter, STM32F103RB microcontroller, PH value acquisition system and stirring control and heating system.

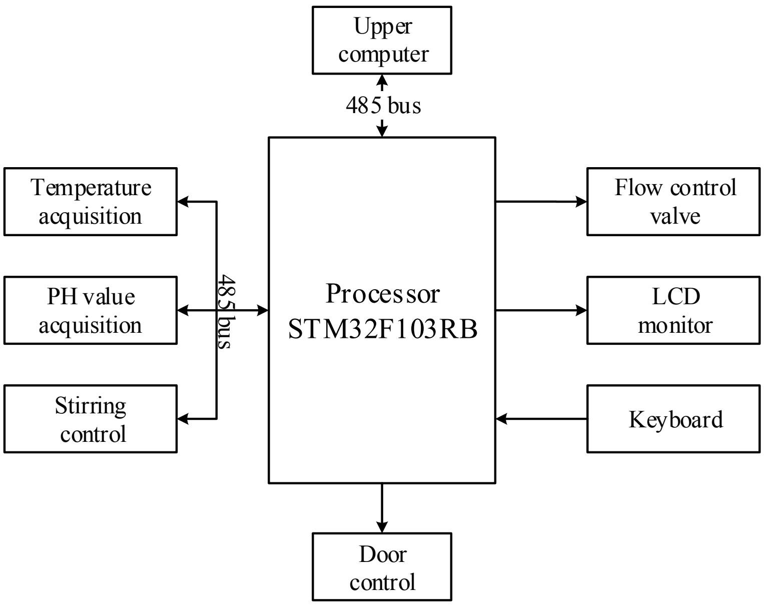

Fig2 The design of system hardware

3. The detection of fermentation tank's temperature and establishment of mathematical model

During fermentation process, the growth of microorganism will dissipate heat and the bulkhead of fermentation tank will absorb or dissipate heat because of weather. Heat can be dissipated by opening door. In summary, the heat produced in fermentation process is called fermentation heat. The fermentation heat includes microorganism heat, stirring heat dissipation, open-door heat dissipation, tank radiation heat (heat dissipation or heat absorption) and so on, which cause the temperature changing. Fermentation heat changes over time. Fermentation temperature is maintained by stirring with door opening to dissipate heat and filling hot water to heat. Regardless of influence of other temperature changing on fermentation temperature, the heat balance equation in fermentation tank can be expressed as [Ruichang, 2005].

$$\begin{aligned} Q_{\text{fermentation}} &= Q_{\text{microorganism}} + Q_{\text{hot water}} - Q_{\text{opening door}} - Q_{\text{stirring}} - Q_{\text{radiation}} \\ &= Q_1 - Q_2 = MC\int \theta dt \end{aligned} \quad (1)$$

where Q_1 represents heat generated during fermentation, its unit J/s; Q_2 represents heat dissipated during fermentation, its unit J/s; M represents the weight of coffee bean, its unit kg; C represents specific heat capacity of coffee bean in fermentation tank, its unit $J/(kg \cdot ℃)$; θ represents temperature in fermentation tank, its unit ℃.

Transfer function in fermentation tank is got by the Laplace transformation of formula (1).

$$G_0(s) = \frac{T(s)}{\Delta Q(s)} = \frac{1}{MCs} = \frac{1}{T_i s} \quad (2)$$

Fermentation tank itself is a complicated controlled object, possessing the characteristics of great inertia, pure time delay, difficulty in controlling time-varying. The temperature in fermentation tank is controlled by door opening to dissipate heat and filling hot water to heat, and its control process has a time lag. In addition, there is a pure time delay in converting temperature signal to electric signal when sensors measure temperature. Other components can be considered as proportional component. Combined with formula (2), this system should be a first-order inertia circulation with a time delay component. The form of this system model is

$$G(s) = \frac{K_s}{T_s + 1} e^{-\tau s}$$

The method to determine the ascending curve of system is as follows.

Make system work in manual condition, after the system balances, add a interfering signal (step signal).The output changes corresponding to a curve which is the ascending curve. The ascending curve recorded by instruments is shown as Figure 3.

It is difficult to find the exact location to determine the parameter for bending of measured curve at the start. Make a tangent on the curve where the slope is maximum, the point of intersection with timeline is pure time delay τ, and the time of the point of intersection with steady state value is the sum of pure time delay and time constant T. The parameters of first-order plants, T and τ are solved.

The comparison of stable output value and step input signal amplitude is the amplification factor of first-order plants, Ks. Based on the obtained curves, three parameters of first-order plants, Ks, T and τ are determined. According to the ascending curve of this system, fermentation tank time constant, T is 180, pure time delay, τ is 60 and the amplification factor, Ks is 5.

Therefore, the mathematical model of this system is $G(s) = \frac{5}{180s+1}e^{-60s}$.

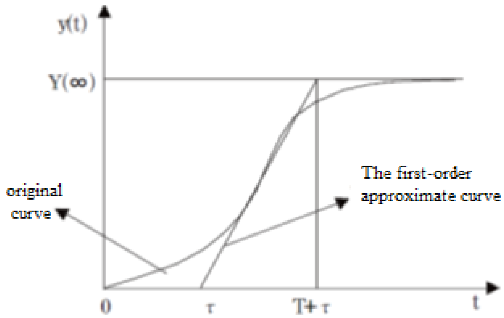

Fig3 The ascending curve of temperature

4. The principle of parameters-self-tuning Furry-PID control algorithm in fermentation tank's temperature and simulation by MATLAB

4.1 The principle of parameters-self-tuning Furry-PID control algorithm

The parameters of traditional PID control system are usually manual tuned, which has some limitations that it can not realize online adjustment, it is hard to describe the experience of the operator accurately and to quantitatively present various signals in control process and evaluation indicators, and it is difficult to build up the mathematical model for some objects. Besides, the change of working condition frequently make control system deviate from the working point, leading to the quality of adjusted system deteriorating. The parameters-self-tuning Furry-PID control algorithm is able to effectively solve the fermentation tank's temperature problem like great inertia, pure time delay, difficulty in controlling time-varying. The fermentation tank's temperature control system is shown in Figure 4.

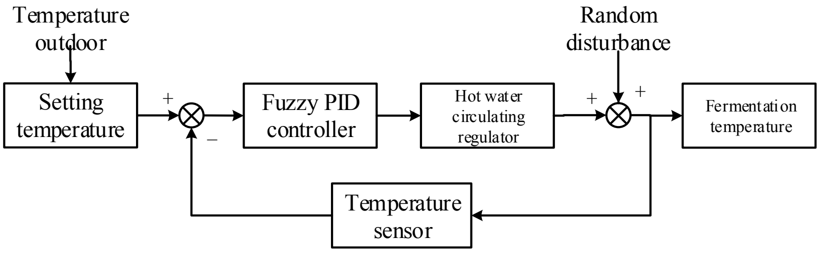

Fig4 Fermentation tank's temperature control system

Furry-PID controller is mainly composed of PID controller in which the parameters might adjust and fuzzy inferior. The fuzzy inferior takes error (e) and change in error (ec) as input and takes three parameters of conventional PID controller, Kp, Ti, Td as output, adopting fuzzy reasoning method to realize adjusting Kp, Ti, Td, finally meeting requirements of parameters self-tuning based on e and ec at different moments. The block diagram is shown in Figure 5.

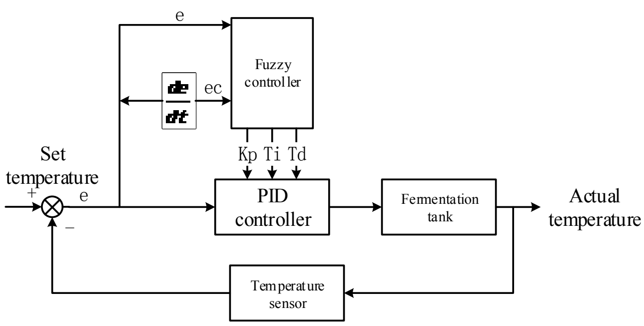

Fig5 The block diagram of parameters-self-tuning PID controller

Table 1 The fuzzy control-rule of ΔKp

e	ec						
	-3	-2	-1	0	+1	+2	+3
-3	+3	+3	+2	+2	+1	0	0
-2	+3	+3	+2	+1	+1	0	-1
-1	+2	+2	+2	+1	0	-1	-1
0	+2	+2	+1	0	-1	-2	-2
+1	+1	+1	0	-1	-1	-2	-2
+2	+1	0	-1	-2	-2	-2	-3
+3	0	0	-2	-2	-2	-3	-3

The domain of definition of fuzzy language variables e, ec, ΔKp, ΔTi and ΔTd is taken [-3, +3]. The membership function of them is determined (adopts the triangle function or trapezoid function), and the fuzzy control-rule table of ΔKp, ΔTi and ΔTd is obtained by different e and ce requirements for PID parameters and experience of field adjustment. Then various combinations are obtained after fuzzy control-rule table quantizes input language variables. Each state of the fuzzy controller input is generated offline through fuzzy logic inference of those combinations. Finally, a fuzzy control table is obtained. The fuzzy control-rule of ΔKp (ΔTi and ΔTd similarly) is given in Table 1.

4.2 The simulation of parameters-self-tuning Furry-PID control algorithm in fermentation tank's temperature by MATLAB

Parameters-self-tuning Furry-PID controller is simulated in the environment of MATLAB/Simulink. The simulation process is as follow.

1) Determine the type and structure of the fuzzy controller; 2) Edit the membership function of input and output variables; 3) Edit the fuzzy control rules; 4) Create the simulation diagram (Take $G(s) = \frac{5}{180s+1}e^{-60s}$ as the transfer function of the system); 5) Before running simulation, load 'Fermentation tank's temperature .FIS' into Fuzzy Logic Controller module by executing commend, READFIS; 6) Run simulation. [Zan *et al.*, 2006] The result is shown in Figure 6.

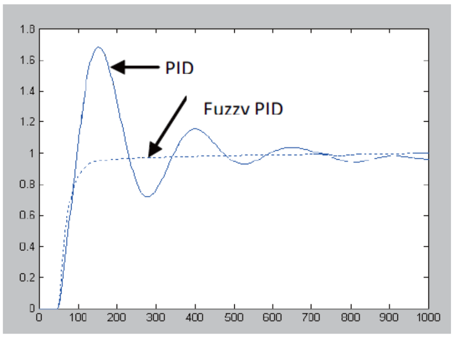

Fig6 Step response of PID and fuzzy PID control

It can be found by analysis of simulation that according to the response curve of traditional PID and parameters-self-tuning Furry-PID control under the unit step signal, the system with parameters-self-tuning Furry-PID control possesses better dynamic response curve, short response time, small overshoot and high precision of stabilization. The system can quickly regain a steady state with the outside interference and has a better dynamic performance.

5. Conclusion

When the coffee fermentation tank's temperature is controlled by parameters-self-tuning Furry-PID combined with PID control and fuzzy control, PID parameters can be adjusted in real time. The experimental simulation and practical application indicate that maximum overshoot is less than <4℃, stabilization precision is ±1 ℃, system possesses high precision of control, better dynamic performance and excellent robustness. In addition, this system demands less data quantity, easy hardware construction and is suitable for microcomputer system. Simple and accurate control method guarantees the quality of coffee bean fermentation and raises economic benefits.

References

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