A Novel Modified PID Controller Applied to Temperature Control with Self-Tuning Ability

Enxiang Yu[1], Yundou Hu[2]

1. College of Engineering, Bohai university, Jinzhou, China
E-mail: bhu_yex@163.com

2. Binzhou Vocational College, Binzhou, China
E-mail: yundouhu@163.com

Abstract: Temperature control is the common problems in the process of industrial production. Because the temperature system is a kind of time-varying nonlinear system, this gives the temperature real-time control has brought the certain difficulty. In order to solve this problem, this paper designed a kind of self-tuning PID control system. It puts the model parameter online identification and controller online design organic unifies in together, parameter identification using fading memory recursive least squares algorithm, and the controller adopts the pole assignment algorithm. This makes the control system not only can online real-time adjustment of parameters, but also ensure that the actual closed-loop system converges to zero pole expectations of zero pole, achieve good control effect. At the same time, aiming at the limitation of the cable temperature measurement technology, this paper designs the wireless acquisition function of multipoint temperature. Simulation results prove the effectiveness of the proposed method.

Key Words: Temperature Control, Pole Assignment Self-tuning PID, Wireless Transmission

1 INTRODUCTION

Temperature is the most common and one of the most important process parameters in the process of industrial production. With the continuous development of industry, temperature detection technology is becoming more and more demanding. Due to some characteristics of the temperature, such as big inertia, serious lag phenomenon, difficult to establish accurate mathematical model, etc, make the poor performance of the control system. With the development of microelectronics technology, computer technology and modern control theory together, make the temperature control system is developing rapidly. Using the computer to apply advanced control algorithms to the temperature control field, greatly improve the performance of the controller and the control precision. In present, lots of methods have been employed to discussed this issue, such as time-varying delays[1-2], networked control[3-4], data driven[5-6] and so on.

This paper adopts self-tuning control scheme, the model parameters online identification and controller online design organic unifies in together, parameter identification using fading memory recursive least squares algorithm. And the controller adopted the pole assignment algorithm makes the control system not only can online real-time adjustment of parameters, but also ensure the actual closed-loop system to converge to the desired zero pole so as to achieve better control effect.

This work is supported by National Nature Science Foundation under Grant (Project No.61304149, 61573071), the National Natural Science Foundation under Liaoning (Project No.2015020042) and the Excellent Talents to Support Projects in Liaoning Province (Project No. LJQ2015003).

2 SYSTEM OVERALL SCHEME DESIGN

Temperature control system includes a multi-point data acquisition, end and receiving end, its way through wireless microprocessor and wireless transmission module and keyboard display module. Data at the receiving end receives the data, through a serial port sent to the PC. Computer System overall structure is shown in Fig.1

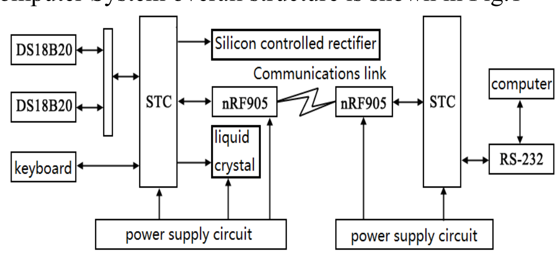

Fig.1: system overall structure

According to the control of this system target, function, reliability, performance, precision and speed, choose on STC microcontroller[7]; Using DS18B20 temperature sensor, the intelligent temperature sensor series mode interference suppression ability, high resolution, good linearity, low cost advantages [8]; Use of nRF905 wireless transceiver module, the module has high communication rate, communicate with micro controller configuration is convenient wait for a characteristic, and low power consumption[9], is advantageous to the dormancy mechanism of this system implementation; Using the infinite power controller circuit control thyristor conduction Angle to achieve power control of electric furnace [10].

3 ADAPTIVE PID CONTROL ALGORITHM

Adaptive control system is a system of a certain ability to adapt, it is able to meet the change of environment conditions, and be measured the information such as dynamic behavior of the system, change of the controlled object and jamming signal etc in a timely manner, and automatically make control decisions, modify the controller structure and parameters, corrective control action, adapt the control signal to the dynamic change of object and disturbance, make the system achieve the optimal or sub-optimal control effect [11].

Adaptive control system is also called the parameter estimation adaptive control, it has two forms: the indirect self-tuning control and self-tuning control directly.

The indirect self-tuning control system includes a process control and process model, calculator controller parameters and controller parameters estimator.

Process model parameters are estimated by measuring the input/output information, estimate the process parameters, then sent to the controller. According to some kind of control strategy design controller, separate the parameter calculation of the controller with the amount of calculation. The former calculator for controller parameters, it is a function of process parameters; the latter is called the adjustable controller, it gives a specific control quantity size. When process parameters are unknown or changing, model parameter identification device can process parameter, and by the controller parameter calculator and adjustable controller to calculate the control parameters and control variables, and then applied to the process. Because the controller is designed according to some strategy of design criterion, so the system can achieve and maintain the desired performance index. This part of process modeling and parameter change, through the model identification to estimate and detection, and through timely adjusting control quantity is overcome, the interference of the system is also can pass the resistance control strategies.

Design of self-tuning control system usually adopts certainty equivalence principle, the object of which is to think of all the unknown parameters with their corresponding estimate instead of after, the control law in the form of a just and object parameters known as stochastic optimal control law of the same form. Therefore, in the design of controller, given all the parameters of the controlled system is known, and according to the given performance index integrated control law, and then estimates of the unknown parameters in the control law with them instead.

Self-tuning control system model parameter estimation method of least squares identification method on the application in the field of system identification has been quite popular, method is also gradually perfect [12].

If the system for differential equation

$$y(k)+a_1 y(k-1)=b_0 u(k-1)+b_1 u(k-2) \tag{1}$$

Use with forgetting factor recursive least squares algorithm, namely formula

$$\hat{\theta}(k+1)=\hat{\theta}(k)+\frac{P(k)\phi(k+1)}{\rho+\phi^T(k+1)P(k)\phi(k+1)}\left[y(k+1)-\phi^T(k+1)\hat{\theta}(k)\right] \tag{2}$$

$$P(k+1)=\frac{1}{\rho}\left[P(k)-\frac{P(k)\phi(k+1)\phi^T(k+1)P(k)}{\rho+\phi^T(k+1)P(k)\phi(k+1)}\right] \tag{3}$$

where $\phi^T(k)=\left[-y(k-1),u(k-1),u(k-2)\right]$ $\theta=\left[a_1,b_0,b_1\right]^T$.

Least squares identification assumes recognition objects under the working conditions in open loop, therefore is suitable for the open loop system. But self-tuning control system must be under the condition of the closed-loop control to identify the parameters of the controlled object. The temperature control system meets the closed loop cognizable conditions [13-14], so the open-loop system identification method can be applied in this system.

In the system control requirements of PID parameter setting is not dependent on the object model, and can be adjusted online and meet the requirements of real-time control. Adaptive PID control is an effective way to solve this problem [15]. Adaptive PID controller parameters adaptive PID control of the main realization way has three: pole assignment adaptive PID controller, destructive principle of adaptive PID controller and the quadratic performance index based adaptive PID controller. Pole assignment design of the main idea is to seek a feedback control law, is located in the hope that the location of the closed-loop transfer function of the pole. It has a design method is intuitive, good dynamic performance and stable system, etc. In the process of temperature control of electric furnace, a controlled object is a big lag. By choosing appropriate expectations pole control effect, pole assignment method enables the system to achieve the optimal or sub-optimal state [16].

Pole assignment self-tuning of PID controller parameters calibration principle is, through the selection of PID parameters, making system with the desired closed-loop characteristic equation. Pole assignment self-tuning PID controller is the most widely used type of adaptive control method, it has the visual design method, the characteristics of good dynamic performance and steady system, its main idea is to seek a feedback control law, is located in the hope that the location of the closed-loop transfer function of the pole.

For discrete incremental PID controller form

$$\begin{aligned}\Delta u(k)&=u(k)-u(k-1)\\&=K_P\left[e(k)-e(k-1)\right]+\frac{K_P T_S}{T_I}e(k)\\&\quad+\frac{K_P T_D}{T_S}\left[e(k)-2e(k-1)+e(k-2)\right]\\&=g_0 e(k)+g_1 e(k-1)+g_2 e(k-2)\end{aligned} \tag{4}$$

Type: T_S as the sampling frequency, and there are

$$\left.\begin{aligned} g_0 &= K_P + \frac{K_P T_D}{T_S} \\ g_1 &= -K_P - 2\frac{K_P T_D}{T_S} + \frac{K_P T_S}{T_I} \\ g_2 &= \frac{K_P T_D}{T_S} \end{aligned}\right\} \quad (5)$$

Thus it can be seen that the PID parameters K_P, T_I and T_D has been replaced by the new controller parameters g_0, g_1 and g_2. For T_I, K_P and T_D adjust, essentially g_0 g_1, and g_2 adjustment.

Set the object for linear time-varying parameter model

$$A\left(z^{-1}\right) y(k) = z^{-d} B\left(z^{-1}\right) u(k) \quad (6)$$

For the incremental digital PID controller structure form, namely

$$G_T\left(z^{-1}\right) = \frac{g_0 G'\left(z^{-1}\right)}{1 - z^{-1}} \quad (7)$$

In order to guarantee the closed-loop stability, join a filter for

$$F'\left(z^{-1}\right) = 1 + f_1 z^{-1} \quad (8)$$

Because the object is open-loop stable minimum phase system, therefore, can make zero on the forward channel transfer function and pole cancellation in processing, even

$$F'\left(z^{-1}\right) = B'\left(z^{-1}\right) \quad (9)$$

Type, for many industrial processes, model order option for $n_a = 2$, $n_b = 1$. In this way, you can easily use PID control parameters, and to configure the poles, even

$$G'\left(z^{-1}\right) = A\left(z^{-1}\right) \quad (10)$$

Thus there are

$$\frac{g_1}{g_0} = a_1 \qquad \frac{g_2}{g_0} = a_2 \qquad f_1 = \frac{b_1}{b_0} \quad (11)$$

Then, the closed-loop transfer function can be simplified to

$$G\left(z^{-1}\right) = \frac{b_0 g_0 z^{-d} / \left(1 - z^{-1}\right)}{1 + b_0 g_0 z^{-d} / \left(1 - z^{-1}\right)} = \frac{b_0 g_0 z^{-d}}{1 - z^{-1} + b_0 g_0 z^{-d}} \quad (12)$$

While PID controller becomes

$$G_T'\left(z^{-1}\right) = \frac{g_0\left(1 + a_1 z^{-1} + a_2 z^{-2}\right)}{\left(1 - z^{-1}\right)\left(1 + {b_1}/{b_0 z^{-1}}\right)} \quad (13)$$

Here, b_0 is constant $(0 < b_0 < 1)$, not to participate in the identification, it is $\hat{a}_1$, $\hat{a}_2$, $\hat{b}_1$, be estimated parameters in the model using the recursive least square method (with forgetting factor) estimates that get the control law of self-tuning PID controller

$$\begin{aligned} u(k) &= u(k-1) + g_0\left[e(k) + \hat{a}_1 e(k-1) + \hat{a}_2 e(k-2)\right] \\ &+ \frac{\hat{b}_1}{b_0}\left[u(k-2) - u(k-1)\right] \end{aligned} \quad (14)$$

As long as b_0, g_0 selecting the appropriate, it can achieve the desired closed-loop poles. As mentioned above, the design principle of this controller is: with estimates of the model parameters are directly involved in the correction of PID parameters and selection of online and used to decide system the expectations of the pole. Therefore, the controller of the control structure is simple, and the control performance and tracking performance are ideal.

I. The simulation results

Experiment with electric furnace temperature control system as an example, input and output of in temperature and real temperature respectively [17]. Therefore, the control system is based on the actual temperature and set temperature difference (i.e., temperature) to control the object implementation regulation. Due to the temperature control process of electric furnace with hysteresis characteristics, can be set in a controlled object characteristics of one-order inertial link with pure hysteresis, a transfer function of controlled objects are as follows:

$$G_P(s) = \frac{K e^{-\tau s}}{T_p s + 1} = \frac{2.5 e^{-10s}}{50s + 1} \quad (15)$$

Among them the gain $K = 2.5$; time constant $T_p = 50$; time delay $\tau = 10$ .With zero order generalized pulse transfer function for a retainer:

$$\begin{aligned} G_P\left(z^{-1}\right) &= z\left(\frac{1 - e^{-\tau s}}{s} \times \frac{K e^{-\tau s}}{T_P s + 1}\right) \\ &= \frac{K\left(1 - e^{-\frac{T}{T_P}}\right) z^{-(N+1)}}{1 - e^{-\frac{T}{T_P}} z^{-1}} = \frac{b_0 z^{-d}}{1 + a_1 z^{-1}} \end{aligned} \quad (16)$$

Type, $b_0 = K\left(1 - e^{-T_S/T_P}\right)$, $a_1 = e^{-T_S/T_P}$, $N = \tau / T_S$; $d = N + 1$.

According to the principle of selecting sampling T_S period [17], the big lag objects, usually choose $T = \tau$, $N = 1$, $d = 2$, will be in control parameters, the measured:

$$G_P\left(z^{-1}\right) = \frac{0.4532 z^{-2}}{1 - 0.8187 z^{-1}} \quad (17)$$

The available $b_0 = 0.4532, a_1 = -0.8187$.

CARMA model of controlled object is:

$$\left(1 - 0.8187 z^{-1}\right) y(k) = 0.4532 z^{-2} u(k) + C\left(z^{-1}\right) e(k) \quad (18)$$

From the viewpoint of pole assignment, usually in a typical second order system closed-loop transfer function of the standard form as the target:

$$G_n(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \quad (19)$$

Characteristic polynomial corresponding discrete characteristic equation as follows:

$$T\left(z^{-1}\right) = 1 + 2e^{-\xi\omega_n T}\cos\left(\omega_n T\sqrt{1 - \xi^2}\right) z^{-1} + e^{-2\xi\omega_n T} z^{-2} \quad (20)$$

Type, ω_n as undamped natural oscillation angular frequency; ξ as the damping ratio. When the second order

system optimum damping ratio $\xi = 0.707$, amount of overshoot in under the action of unit step $\sigma = 4.3\%$, phase Angle stability margin $\gamma(\omega_c) = 65.5°$, for the second order optimal dynamic response model.
Sampling period and relationship[18]:

$$T_S = \frac{2\pi}{\omega_n N_T}\sqrt{1-\xi^2} \qquad (N_T = 5-10) \tag{21}$$

Once $N_T = 5$, then $\xi = 0.707$, $T_S = 10s$, $\omega_n = 0.015s^{-1}$.
The expectation characteristic polynomial for:

$$T\left(z^{-1}\right) = 1 - 1.789z^{-1} + 0.8089z^{-2} \tag{22}$$

Should avoid mutate and cause oscillation in the system output end, so the choice

$$C\left(z^{-1}\right) = 1 + C_1 z^{-1} + C_2 z^{-2} = 1 + 0.5z^{-1} + 0.1z^{-2} \tag{23}$$

In a digital system, usually adopts PID controller with digital filter algorithm, such as

$$u\left(z^{-1}\right) = \frac{g_0 + g_1 z^{-1} + g_2 z^{-2}}{\left(1-z^{-1}\right)\left(1+f_1 z^{-1}\right)} e\left(z^{-1}\right) \tag{24}$$

Type,

$$g_0 = K_P\left(1 + \frac{T_D}{T_S}\right);$$

$$g_1 = -K_P\left(1 + 2\frac{T_D}{T_S} - \frac{T_S}{T_I}\right);$$

$$g_2 = K_P \frac{T_D}{T_S}$$

Solutions of equations K_P , T_I , T_D , and the only solution, namely

$$\left.\begin{aligned} K_P &= (g_0 - g_2) \\ T_I &= \frac{g_0 - g_2}{g_0 + g_1 + g_2} T \\ T_D &= \frac{g_2}{g_0 - g_2} T \end{aligned}\right\} \tag{25}$$

Convert pole assignment PID self-tuning controller into incremental PID controller, can choose the following form:

$$F\left(z^{-1}\right) = \left(1 - z^{-1}\right)\left(1 + f_1 z^{-1}\right) \tag{26}$$

$$G\left(z^{-1}\right) = g_0 + g_1 z^{-1} + g_2 z^{-2} \tag{27}$$

Can get the following equation was established

$$\begin{aligned} &\left(1 - 0.8187z^{-1}\right)\left(1 - z^{-1}\right)\left(1 + f_1 z^{-1}\right) \\ &+0.4532z^{-2}\left(g_0 + g_1 z^{-1} + g_2 z^{-2}\right) \\ &= \left(1 - 1.7886z^{-1} + 0.8089z^{-2}\right)\left(1 + 0.5z^{-1} + 0.1z^{-2}\right) \end{aligned} \tag{28}$$

To the coefficient is equal on both sides of the equation, solving algebraic equation

$f_1 = 0.5301$; $g_0 = 0.3529$;

$g_1 = -0.4599$; $g_2 = 0.1785$

There are:

$$\begin{aligned} u\left(z^{-1}\right) &= \frac{G\left(z^{-1}\right)}{F\left(z^{-1}\right)} e\left(z^{-1}\right) \\ &= \frac{0.3529 - 0.4599 g_1 z^{-1} + 0.1785z^{-2}}{\left(1 - z^{-1}\right)\left(1 + 0.5301z^{-1}\right)} e\left(z^{-1}\right) \end{aligned} \tag{29}$$

Computer through the analysis of the controlled quantity $u(t)$ and the output quantity $y(t)$, the online identification for controlled object [12], it is concluded that the parameter values, into these parameters, the corresponding PID controller parameters can be obtained

$$K_P = 0.1744 ; T_I = 24.41 ; T_D = 10.24 \tag{30}$$

Through MATLAB Simulink simulation tool for the control system simulation, set the temperature setting of the furnace for step input50 ° C, the system response curve is shown in Fig.2 (a). When the control object is affected by interference or the external environment, the system response curve is shown in Fig.2 (b).

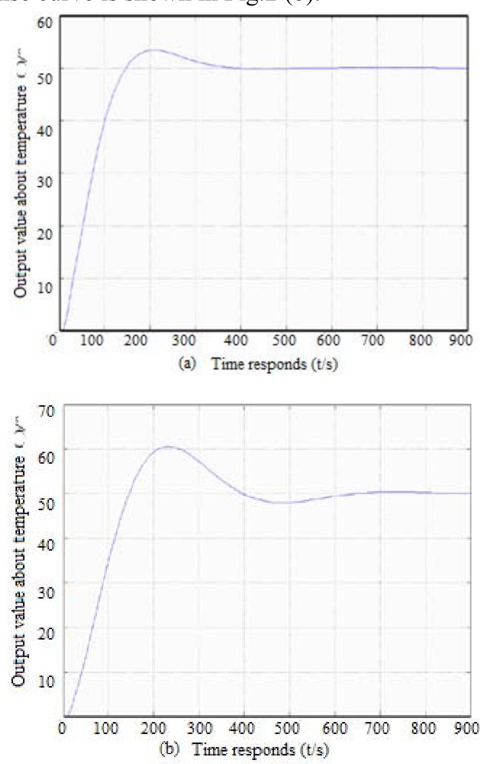

Figure 2: system simulation response curve

Model in the system because of the influence of the outside world changes, pole assignment self-tuning PID controller for the system to identify the object online, calculate the suitable parameters:

$g_0 = 0.9977$; $g_1 = -1.1701$; $g_2 = 0.2875$

Can get a new PID controller parameters for:

$K_P = 0.7101$; $T_I = 61.7$; $T_D = 4.049$

Using PID parameters on the system simulation, it is concluded that the system response curve is shown in Fig.3.

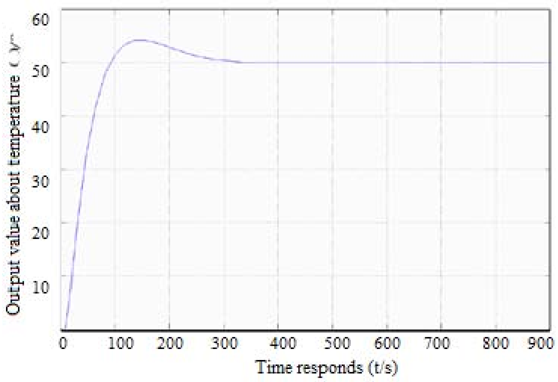

Fig.3: furnace system response curve

Prove the validity of the pole assignment method to design PID controller.

System software mainly includes the realization of the system function and the realization of the control algorithm. The realization of the function of system is mainly composed of three parts: input signal is read, display and output control, information transmission. Read the input signal including switch input signal and the temperature sensor and the analog input signal is read; output control signals including switch output control; information display and transfer including equipment operation instructions and at room temperature, the temperature measured values or value the digital display and equipment running status Settings, etc., and the transmission of the information. The realization of the control algorithm is mainly based on the system input and output quantity and the acquisition of certain system parameters, and the corresponding control algorithm through the data analysis and calculation, by adjusting the control volume, to realize the real-time control of the controlled object.

4 CONCLUSION

This paper discusses the design method of temperature control system this paper proposes a new adaptive PID control algorithm, pole assignment self-tuning PID control algorithm. Proved by theoretical calculation and simulation, the algorithm has good self to controlled object recognition. When there is interference of the controlled object, the system model parameters change, the algorithm is based on the input and output analysis, it is concluded that the new system model parameters, and modify the PID control parameters, enables the system to achieve the best running state

REFERENCES

[1] X. Li and H. Gao. A new model transformation of discrete-time systems with time-varying delay and its application to stability analysis. IEEE Trans. Autom. Control, 56(9):2172--2178, 2011

[2] X Xie, S Yin, H Gao, O Kaynak. Asymptotic stability and stabilisation of uncertain delta operator systems with time-varying delays. IET Control Theory & Applications, 7(8):1071-1078,2013

[3] H. Gao, T. Chen, J. Lam. A new delay system approach to network based control. Automatica. 2008, 44: 39-52

[4] S. Ding, P. Zhang, S. Yin, E. Ding , An integrated design framework of fault-tolerant wireless networked control systems for industrial automatic control applications, IEEE Transactions on Industrial Informatics, 9(1): 462-471, 2013

[5] S. Yin, G. Wang, H. Karimi, Data-driven design of robust fault detection system for wind turbines, Mechatronics, DOI:10.1016/j.mechatronics. 2013.11.009, 2013.

[6] S. Yin, S. Ding, A. Haghani, H. Hao, Data-driven monitoring for stochastic systems and its application on batch process, International Journal of Systems Science, 44(7):1366 -1376, 2013.

[7] Y. Q. Yu , M. H. Wang, Overwhelmed with. Single chip microcomputer application in the control system [M]. Electronic industry press. 2005: (5-8).

[8] J. Q. Liu, Electronic components identification and detection technology [M]. National defense industry press, 2007:133-137).

[9] Z. W. Huang, Single chip wireless transceiver integrated circuit principle and application [M]. People's posts and telecommunications publishing house, 2004 (1-3).

[10] G. X. Liu, Y. Q. Zhao, Promise power controller based on 89 s52 microcontroller design [J]. Microcomputer information, 2007, 23 (1).

[11] H. R. Zhang, High south, G. Z. Wang Controller parameters adaptive adjusting [J]. Journal of radio communication technology, 2003, 29 (1).

[12] J. Deng, S. Cong, Several self-tuning control in control engineering application and performance of the comparative study [J]. Journal of system simulation technology and its applications, 2003, 8 (2-3)

[13] X. F. Wang, L. G. Zhang, Modeling and identification system [M]. Electronic industry press, 2004: (54-57).

[14] C. Z. Yang, C. Z. Sun, H. Di, C. S. Zhang. System identification and adaptive control [M]. Chongqing university press, 2003:120-123).

[15] T. Y. Hua, Y. Y. Xin, G. L. Sheng, New PID control and its application [M]. Mechanical industry publishing house, 1998 (27-32).

[16] X. Y. Xu, Adaptive control theory and application [M]. Electronic industry press, 2007: (45-51).

[17] J. M. Wang, J. Mao, Resistance furnace temperature control system design [J]. Journal of forging technology, 2009, 30 (1).

[18] Q. Yang, J. Xie, J. Zhi, Zero pole assignment self-tuning temperature control of the modeling and simulation [J]. Journal of chongqing university, 2006, 29 (6)