*Journal on Internet of Things*
DOI:10.32604/jiot.2020.010226

Tech Science Press

*Article*

# Parameters Optimization of the Heating Furnace Control Systems Based on BP Neural Network Improved by Genetic Algorithm

**Qiong Wang*  and Xiaokan Wang**

Henan Mechanical and Electrical Vocational College, Zhengzhou, 451191, China
*Corresponding Author: Qiong Wang. Email: zmwxy@163.com
Received: 01 January 2020; Accepted: 05 May 2020

**Abstract:** The heating technological requirement of the conventional PID control is difficult to guarantee which based on the precise mathematical model, because the heating furnace for heating treatment with the big inertia, the pure time delay and nonlinear time-varying. Proposed one kind optimized variable method of PID controller based on the genetic algorithm with improved BP network that better realized the completely automatic intelligent control of the entire thermal process than the classics critical purporting (Z-N) method. A heating furnace for the object was simulated with MATLAB, simulation results show that the control system has the quicker response characteristic, the better dynamic characteristic and the quite stronger robustness, which has some promotional value for the control of industrial furnace.

**Keywords:** Genetic algorithm; parameter optimization; PID control; BP neural network; heating furnace

## 1 Introduction

The conventional PID control has been widely applied because of it is good robustness and simple structure, in the industrial control used. Making P (proportion deviation, I (integral deviation) and D (differential deviation) into the linear combination is the basic idea of PID control so that it could control the controlled object. Therefore the system's performance is controlled by these three parameters. But the conventional PID control parameters are not adjusted online which is difficult to adapt to the object changes; except the PID parameters are also difficult to achieve the optimal state for the higher order or the strong coupling multivariable system which limited by the setting condition, as well as the object dynamic characteristic changes along with the environment [1–3] .

Proposed the BP neural network method with self-organized, self-learning and other advantages to adjustment the controller parameter online, it could meet the control requirements. BP neural network may easily lead to local minimum because of it is learning process is slow. In this paper, optimized the network threshold value and the weight by combining the genetic algorithm and the improved BP algorithm to avoid their falling into local minimum point [4–5].

## 2 PID Control of the Heating Furnace

Control system of the heating furnace is shown in Fig. 1, the PID control rule is often used in the system control rule.

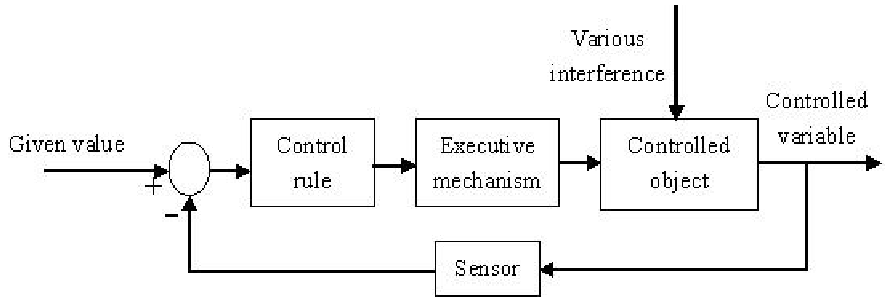


**Figure 1:** Schematic of the heating furnace control system

Supposed the mathematical model of heating furnace is:

$$G_p = 3/(4s+1) \tag{1}$$

The flow diagram of PID control process can be expressed in Fig. 2.

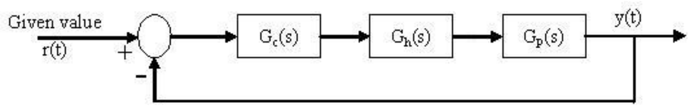


**Figure 2:** PID control system

where,

$$G_c = K_p(1 + K_i / s + K_d s) \tag{2}$$

$$G_A = (1 - e^{-\tau s}) / s \tag{3}$$

We can get the results: $Kp$ = 2.236, Ki = 0.870, $Kd$ = 0.267

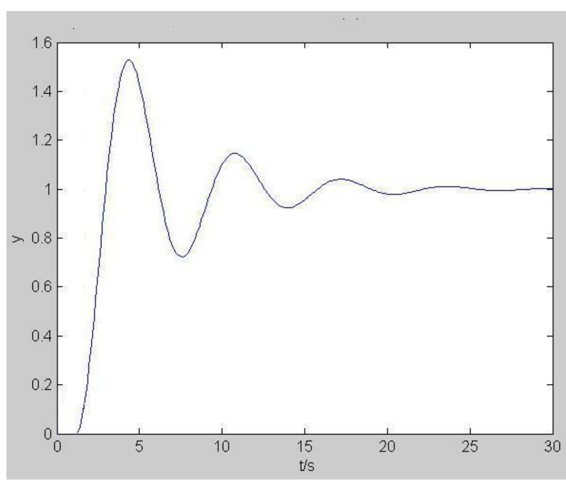


**Figure 3:** Z-N tuning of the control curve

By using parameter tuning method, that is the classical-the proportion of degrees to tuning the above closed-loop system parameters. the simulation curve is shown in Fig. 3 if the reference input is unit step signal [6].

Simulation curve shows that the Z-N tuning parameter control method is not better with big overshoot and long oscillation time which is difficult to achieve with online adjustment of PID parameters [7-8], so the method should not be used to control the parameters of heating furnace online.

## 3 Optimization Tuning of BP Neural Network PID Controller Parameters Based on the Improved Genetic Algorithm

The self-tuning PID controller of the heating furnace control system with neural network which does not rely on the knowledge of object model. When the network structure is established, the control function whether meet the requirements of control process that depends entirely on the learning algorithm [9–12].

### *3.1 Realization of Improved Genetic Algorithm*

Generally BP network structure is shown in Fig. 4, the algorithm steps are:

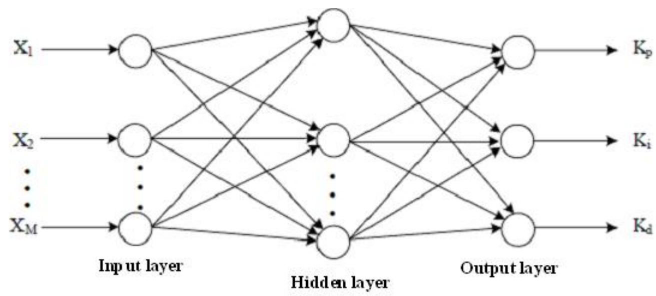


**Figure 4:** BP network structure

(1) Input the training samples and get the output by the network structure;

(2) Get the error by comparing the actual output and the desired output according to the error threshold and weight regulation;

(3) Repeat the above two steps until the error up could meet the control requirements.

Studies show that the BP algorithm gradually could adjust the weights and threshold of the algorithm which may result in slow learning process, excessively long training time, and easily fall into local minimum and not able to obtain the best distribution of weights and thresholds. To speed up the learning rate, BP has made some optimization algorithm, such as dynamic learning factor and inertial factor. These methods are more significant in accelerating the convergence speed of the network and avoiding falling into local minimum than others. The genetic algorithm does not request the objective function which has the continuity, moreover it may realize global optimization of the complex multi-peaks, the nonlinear and non-differentiable functions that easy to obtain the globally optimal solution or the second-best solution with better performance [13–14]. Combined the genetic algorithm and the BP algorithm will obtain the solutions of global optimization and accuracy [15–17]. The algorithm process is:

(1) Generated initial population by coding the weight and threshold based on the optimized multi-parameter mapping coding;

(2) Calculate the fitness value;

(3) If the contemporary individuals generate new individuals by crossing, selection and mutation, and if the algorithm process does not meet the GA stop conditions, please switch (2); otherwise, please switch (4);

(4) Finding a better solution space for the genetic algorithm to and using BP algorithm to search out the optimal solution from all these small solution space [18–21].

### *3.2 PID Parameters Optimization*

Classic incremental PID control algorithm is:

$$u(k) = u(k-1) + k_p[e(k) - e(k-1)] + k_i e(k) + k_d[e(k) - 2e(k-1) + e(k-2)] \quad (4)$$

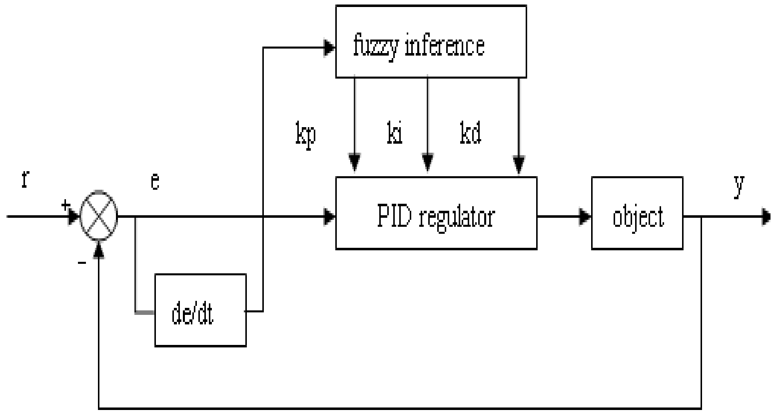


**Figure 5:** Tuning PID parameters of the BP Network

Here are the steps of the algorithm:

(1) Determined the network structure which using the 3-4-3 structure, the inputs are respectively, *e (k), e (k)-e (k-1), e (k)-2e (k-1) e (k -2)*, and the output are the *Kp, Ki, Kd*;

(2) Select the initial population N = 60, crossover probability Pc = 0.08, weight, range and threshold initialization [22–26];

Select the objective function of (absolute deviation points:

$$J = \int_0^\infty |e(t)| dt \tag{5}$$

The fitness function is:

$$J = 1 / \int_0^\infty |e(t)| dt \tag{6}$$

(3) Get the sampled *r (k)* and *y(k)* and calculate the error at this time;

(4) The network self-learning and online adjusting the weight and threshold; calculate the input and output of each layer neural network and obtain the three adjustable parameters *Kp, Ki, Kd*; Calculate the system output;

(5) If the calculated fitness of the algorithm is not meet the system requirements, please turn into the Step 3;

(6) Find the most optimal *Kp, Ki, Kd* and simulating the system.

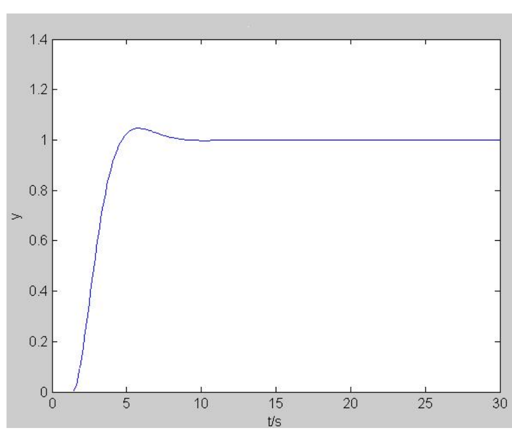


**Figure 6:** The tuning curve of BP neural network control

Simulation results show that the BP neural network by tuning with PID control system has a faster response, better dynamic characteristics and stronger robustness than the classic critical proportioning (Z-N) method [25–26].

## 4 Conclusion

Optimized BP neural network with self-organized and self-learning based on improved genetic algorithm carries on the optimization of controller parameter that could make up the insufficiency of BP neural network which is slow convergence of learning process and easily fall into local-level minimax. It could adjust the controller parameters online according to the object changes. So the method could satisfy the dynamic characteristics of the control object which changes along with the environmental variation that achieve good control effect.

**Acknowledgement:** This work was supported by the youth backbone teachers training program of Henan colleges and universities under Grant No. 2016ggjs-287, and the project of science and technology of Henan province under Grant No. 172102210124，and the Key Scientific Research projects in Colleges and Universities in Henan (Grant No. 18B460003).

**Funding Statement:** The authors received no specific funding for this study.

**Conflicts of Interest:** The authors declare that they have no conflicts of interest to report regarding the present study.

## References

[1] D. Shi, G. Gao, Z. Gao, P. Xiao, "Temperature control system of resistance-heated furnace based on variable fuzzy-pi control," *Energy Procedia*, vol. 11, no. 2, pp. 1186-1191, 2013.

[2] J. Su, Z. Sheng, L. Xie, G. Li, A. X. Liu, "Fast splitting-based tag identification algorithm for anti-collision in uhf RFID system," *IEEE Transactions on Communications*, vol. 67, no. 3, pp. 2527-2538, 2018.

[3] L. Han, Z. Y. Zhang, "The application of immune genetic algorithm in main steam temperature of PID control of BP network," *Physics Procedia*, vol. 24, no. 1, pp. 80-86, 2012.

[4] L. Ji, X. F. Lian, "Application of blow-off wind tunnel control based on genetic algorithm optimized BP-NEURAL network PID neural network," *Applied Mechanics & Materials*, vol. 65, no. 310, pp. 557-559, 2013.

[5] Q. Zhang, H. B. Wu, X. W. Jin, "Optimization of cottonseed meal de-gossypol process by extrusion via genetic algorithm based on artificial neural network," *Animal Husbandry and Feed Science*, vol. 52, no. 1, pp. 51-53, 2016.

[6] J. Su, Z. Sheng, A. Liu, Y. Han, Y. Chen, "A group-based binary splitting algorithm for UHF RFID anti-collision systems," *IEEE Transactions on Communications*, vol. 68, no. 2, pp. 998-1012, 2019.

[7] J. S. Wu, "Hybrid optimization algorithm to combine neural network for rainfall-runoff modeling," *International Journal of Computational Intelligence & Applications*, vol. 15, no. 3, pp.165-168, 2016.

[8] S. C. Miao, J. H. Yang, X. H. Wang, J. C. Li, T. L. Li, "Blade pattern optimization of the hydraulic turbine based on neural network and genetic algorithm," *Hangkong Dongli Xuebao/Journal of Aerospace Power*, vol. 30, no. 8, pp. 1918-1925, 2015.

[9] S. Qu, H. Yang, "Infrared image segmentation based on PCNN with genetic algorithm parameter optimization," *Qiangjiguang Yu Lizishu/High Power Laser and Particle Beams*, vol. 27, no. 5, pp. 32-37, 2015.

[10] J. Su, Y. Chen, Z. Sheng, Z. Huang, A. Liu, "From M-ary query to bit query: a new strategy for efficient large-scale RFID identification," *IEEE Transactions on Communications*, pp. 1-13, 2020.

[11] A. Majumdar, D. Ghosh, "Genetic algorithm parameter optimization using Taguchi robust design for multi-response optimization of experimental and historical data," *International Journal of Computer Applications*, vol. 127, no. 5, pp. 26-32, 2015.

[12] M. V. Prabhu, R. Karthikeyan, M. Shanmugaprakash, “Modeling and optimization by response surface methodology and neural network-genetic algorithm for decolonization of real textile dye effluent using Pleurotus ostreatus: a comparison study,” *Desalination & Water Treatment*, vol. 57, no. 28, pp. 13005-13019, 2016.

[13] H. Alexander, B. Michael, “Parameter optimization of thermoelectric modules using a genetic algorithm,” *Applied Energy*, vol. 155, no. 5, pp. 447-454, 2015.

[14] Y. Liu, Y. Li, L. Hua, H. Mao, “Rapidly cylinder hydraulic servo system design and optimization of PID control based on genetic algorithm,” *Journal of Wuhan University of Technology(Transportation Science & Engineering),* vol. 41, no. 1, pp. 52-56 and 63, 2017.

[15] G. Zhang, H. Qi, H. Jia, “Parameter optimization of agent pid motion controller based on pole assignment,” *Zhongshan Daxue Xuebao/acta Scientiarum Natralium Universitatis Sunyatseni,* vol. 54, no. 4, pp. 23-28 and 36, 2015.

[16] M. Kaibalya, M. Tamoghna, S. Henrik, C. Nirupam, “Multiple criteria in a top gas recycling blast furnace optimized through a k -optimality-based genetic algorithm,” *Steel Research International,* vol. 87, no. 10, pp. 1284-1294, 2016.

[17] S. Chiappone, O. Giuffrè, A. Granà, R. Mauro, A. Sferlazza, “Traffic simulation models calibration using speed–density relationship: an automated procedure based on genetic algorithm,” *Expert Systems with Applications An International Journal,* vol. 44, no. C, pp. 147-155, 2016.

[18] X. C. Luo, Z. Yang, “Dual strategy for 2 - dimensional PDE optimal control problem in the reheating furnace,” *Optimal Control Applications & Methods,* vol. 39, no. 2, pp. 981-996, 2017.

[19] K. Chen, H. L. Ke, L. He, Y. H. Peng, “A novel numerical model for billet reheating furnace,” *Ironmaking & Steelmaking Processes Products & Applications,* vol. 44, no. 6, pp. 1-8, 2017.

[20] J. Su, Z. Sheng, A. Liu, Y. Han, Y. Chen, “A time and energy saving based frame adjustment strategy (TES-FAS) tag identification algorithm for UHF RFID systems.” *IEEE Transactions on Wireless Communications,* pp. 1-13, 2020.

[21] M. M. Gani, M. S. Islam, A. U. Muhammad, “Optimal PID tuning for controlling the temperature of electric furnace by genetic algorithm,” *SN Applied Sciences,* vol. 1, no. 8, pp. 880, 2019.

[22] H. M. Unver, U. Unver, A. Kelesoglu, “Introduction of a novel design approach for tunnel-type induction furnace coil for Aluminium Billet Heating,” Arabian *Journal for Science & Engineering,*vol. 24, no. 2, pp. 1-9, 2017.

[23] H. B. Cong, L. X. Zhao, H. B. Meng, Z. L. Yao, “Monitoring and control system development for pilot-scale moving bed biomass carbonization equipment with internal heating,” *Transactions of the Chinese Society of Agricultural Engineering,* vol. 31, no. 3, pp. 268-274, 2015.

[24] J. Su, Z. Sheng, V. C.M. Leung, Y. Chen, “Energy efficient tag identification algorithms for RFID: survey, motivation and new design,” *IEEE Wireless Communications,* vol. 26, no. 3, pp. 118-124, 2019.

[25] R. D. Zhang, J. L. Tao, “A nonlinear fuzzy neural network modeling approach using improved genetic algorithm,” *IEEE Transactions on Industrial Electronics,* vol. 125, no. 99, pp.1-1, 2017.

[26] N. A. Spirin, O. P. Onorin, A. S. Istomin, V. V. Lavrov, I. A. Gurin, “Study of transition processes of blast-furnace smelting by the mathematical model method,” *Series Materials Science and Engineering,* vol. 3, no. 411, pp. 12-16, 2018.