Research on temperature control system of distillation column based on ABC-PID

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Abstract. The existence of non-linearity and variable parameters in distillation column system makes it difficult to tune the parameters of PID controller in its control system. The artificial bee colony algorithm is applied to the temperature control system of distillation column to optimize the PID parameters. The specific process of optimizing PID parameters based on artificial bee colony algorithm is put forward. PID controller optimized by artificial bee colony algorithm and traditional PID controller are separately used to control temperature coupling system of distillation column. The performance comparison and analysis are carried out by simulation. The results show that the temperature response curve of the PID controller based on artificial bee colony algorithm has smaller overshoot and the system has better robustness, verified the superiority of the artificial bee colony algorithm in optimizing the PID controller of distillation column.

1. Introduction
Rectification is the most common and important operation unit in chemical engineering process. Therefore, the control of distillation column has been a research hotspot in chemical industry. Because the distillation column is a multi-variable control system, the internal mechanism is complex, the coupling between variables is serious, the response to control action is slow, the hysteresis is serious, and has the characteristics of large random disturbance, the traditional PID control is difficult to obtain satisfactory control effect. Intelligent PID control is of great significance for improving economic benefit of distillation column.

Artificial Bee Colony Algorithm is an intelligent algorithm to simulate bee’s honey harvesting behavior. Due to the characteristics of simple implementation, easy calculation, strong robustness and few control parameters, Artificial Bee Colony Algorithm has attracted more and more attention. Simulation results show that the Artificial Bee Colony Algorithm is very suitable for PID parameter setting [1].

This paper presents a parameter optimization method of PID controller for MIMO system of distillation column based on Artificial Bee Colony Algorithm. By comparing the performance of simulation with traditional PID control, the optimization performance and convergence characteristics are observed to verify the feasibility and effectiveness of applying artificial bee colony algorithm to temperature control system of distillation column.
2. Distillation column decoupling control system

2.1. Coupling principle

The distillation column is a kind of tower-type vapor-liquid contact device for rectification. When the product quality at the top and bottom of distillation column need to reach certain quality indexes, the quality control system of the products at the top and bottom of the column needs to be set up. The temperature at the bottom of the tower is taken as the indirect quality index of the products at the bottom of the tower, and the temperature at the top of the tower is taken as the indirect quality index of the products at the top of the tower. Control the top temperature of the tower by quantity of reflux to ensure the product composition, the bottom temperature of the tower is controlled by the steam flow rate heated by the bottom reboiler to ensure the bottom product composition.

From the internal mechanism of distillation column operation, when the top reflux is changed, not only the top temperature but also the bottom temperature will be changed, of course, the top product components and bottom product components will also be changed. Similarly, when the heating vapor flow rate at the bottom of the tower is disturbed, the temperature in the tower will change, which will not only change the composition of the products at the bottom of the tower, but also affect the composition of the products at the top of the tower. Obviously, there is a coupling between the two control systems at the top and the bottom of the tower. Therefore, the product quality decoupling control system at both ends of tower is designed as follows [2]:

![Distillation column decoupling control system](image)

**Figure 1.** sketch of product quality decoupling control system at both ends

Figure 1 is a sketch of product quality decoupling control system at both ends. In the figure, both T1C and T2C are PID controllers, and the effect of quantity of reflux on bottom components can be compensated by decoupling link, the steam valve can work in time. Similarly, the change of steam flow only affects bottom components, while its effect on top components can be compensated by pre-operation of reflux valve through another decoupling link, thus achieving decoupling control of product quality at both ends. The performance of the PID controller has a great influence on the control effect of the system. Therefore, optimizing the PID controller of the distillation column plays an important role in improving the performance of the distillation column control system.

3. Artificial bee colony algorithm

3.1. Algorithm basic principles

Artificial bee colony algorithm is a kind of optimization method which highlights the global optimization results through the local optimization behavior of individual bees. It has the characteristics of fast convergence. In each iteration, global and local searches are carried out, which
greatly increases the probability of finding the optimal solution, avoids the local optimum to a large extent, and has strong robustness and adaptability. Therefore, this paper considers introducing artificial bee colony algorithm into distillation column control system to optimize the parameters of PID controller.

Artificial bee colony algorithm is described as follows: Firstly, honey source is introduced, which represents all possible solutions in the solution space, and the honey source is measured by the digital quantity "profitability" or fitness function value. Three kinds of bees: bee-picking, following bee and scouting bee. Bee-picking is associated with specific sources of honey that they are currently collecting. Bee-picking shares information with other bees by wagging dance. Following bees wait in the dance area to make choices about food sources by sharing information about bee-picking. Bee-picking always remembers its previous optimal location and searches its neighborhood according to memory. The role of Scout bees is to search for a new location at random.

ABC algorithm model includes three basic elements: bee source, employed foragers (bee-picking) and unemployed foragers (scout bee and follower bee); two basic behavior models: recruiting bees for food source and abandoning a certain food source.

Assuming that the total number of bees is $N_s$, the population size of bee-picking and following bee is equal to $N_e$, and the dimension of individual vector is $D$.

Initially, the bee searches randomly as a scout bee and generates $N_s$ honey sources (feasible solutions) randomly. The specific feasible solution $x_i$ generated randomly is

$$x_i = x_{\min}^i + \text{rand}(x_{\max}^i - x_{\min}^i)$$

In this formula, $j \in \{1, 2, \cdots, D\}$ is a component of the $D$ dimensional solution vector and $\text{rand}$ is a random number among $[0, 1]$.

After finding the source of honey, the scout bee converts to picking bees and interacts with the following bee. bee-picking continue to collect honey near the original source (local search process), looking for other new sources and calculating their fitness (profitability). If the profitability is high, bees will replace the original source with new sources by greed criterion.

For each follower bee, according to the probability proportional to the fitness value of the honey source, a honey source is selected and picked nearby to find other honey sources. If the income is high, the follower bee is converted to bee-picking, and the original honey source is replaced by new sources.

Neighborhood search in situ to generate new honey sources:

$$v_i = w \times x_i^i + \varphi (x_{\max}^i - x_{\min}^i)$$

$$w = we + (ws - we) \times \cos \left( \frac{pi/2}{t/M} \right)$$

In this formula, $j \in \{1, 2, \cdots, D\}$, $k \in \{1, 2, \cdots, N_e\}$, $t \in \{1, 2, \cdots, M\}$, and $k \neq i$, $M$ is the number of iterations, $k$ and $j$ are generated randomly, and $\varphi$ is the random number among $[-1, 1]$.

Bees adopt greedy selection method to compare the fitness of honey source $v_i^i$ and $x_i^i$ keep the fitness better. Each follower bee chooses honey source with the following probability:

$$p_i = \frac{\text{fit}_i}{\sum_{j=1}^{N_s} \text{fit}_i}$$
$fit_i$ is the fitness value of the $i$th honey source, $N_s$ is the number of honey sources (solutions).

If the number ($Bas$) of bee-picking and bee-following searches exceeds the limit number of times $a$, and the bee source with higher adaptability is still not found, then the bee source is abandoned. At the same time, the role of bee is changed from bee-picking or bee-following to bee-detecting, and a new bee source is generated randomly:

$$x^j_i = x^j_{\text{min}} + \text{rand}(x^j_{\text{max}} - x^j_{\text{min}}), \quad Bas_j \geq \text{Limit}$$

If the stopping criterion is satisfied, the calculation is stopped and the optimal fitness value and corresponding parameters are output [3–4].

3.2. ABC optimized PID controller

By combining the artificial bee colony algorithm with the PID control, and using a set of parameters ($p_k$, $i_k$, $d_k$) of the PID controller as a honey source of the artificial bee colony algorithm, the parameter tuning problem of the PID controller can be transformed into the optimization process of the artificial bee colony algorithm with three-dimensional vectors.

Before optimizing the artificial bee colony algorithm, it is necessary to determine how to take the performance index of the PID controller as the objective function [5]. Select the absolute error time integration performance index ($ITAE$) as the objective function.

$$J = ITAE = \int_0^\infty t|e(t)| \, dt$$

The fitness of honey source can be calculated by the following formula:

$$fit_i = \frac{1}{1 + J_i}$$
4. Realization and analysis of simulation

4.1. Simulink model construction

In the figure, \( N_{21}(s) \) and \( N_{12}(s) \) are feedforward decoupling links. In order to realize the decoupling between \( U_1(s) \), \( Y_2(s) \), \( U_2(s) \) and \( Y_1(s) \), according to the invariance principle, we can get:

\[
U_1(s)G_{21}(s) + U_1(s)N_{21}(s)G_{22}(s) = 0 \tag{8}
\]

\[
U_2(s)G_{12}(s) + U_2(s)N_{12}(s)G_{11}(s) = 0 \tag{9}
\]

4.2. Simulation realization

The temperature decoupling control system of the top and bottom of the distillation column is taken as the controlled object, and the transfer function matrix of the mathematical model is the following:

\[
G(s) = \begin{bmatrix} 0.66e^{-s} & -0.32e^{-s} \\ 5.7s + 1 & 7.06s + 1 \\ 0.49e^{-s} & 0.87e^{-s} \\ 8.09s + 1 & 3.89s + 1 \end{bmatrix} \tag{10}
\]

Decoupling link:

\[
N_{21}(s) = -\frac{G_{21}(s)}{G_{22}(s)} = \frac{-1.85s - 0.49}{7.09s + 0.87} \tag{11}
\]

\[
N_{12}(s) = -\frac{G_{12}(s)}{G_{11}(s)} = \frac{1.824s + 0.32}{4.66s + 0.66} \tag{12}
\]
The top temperature setting value is 30 and the bottom temperature setting value is 50. At 200 s, the top temperature setting value is disturbed and the disturbance value is 40. At 300 s, the bottom temperature setting value is disturbed and the disturbance value is 40. At 400 s, the top temperature process value is disturbed and the disturbance value is 10. At 500 s, the bottom temperature process value is disturbed and the disturbance value is -10.

In this paper, we set the bee number of ABC algorithm to be 30, the number of iterations $M=100$, and the weight is $w_c = 0.4$, $w_s = 0.9$. The optimal parameters are the top PID controller $k_p = 1.20$, $k_i = 0.19$ and bottom PID controller $k_p = 0.60$, $k_i = 0.12$. The simulation results of MATLAB/Simulink are as follows:

The figure shows that when the number of iterations reaches 63, the optimal function value $J$ converges basically.

![Figure 4. Temperature curve of tower bottom based on conventional decoupling control](image1)

![Figure 5. Temperature curve of tower bottom based on ABC-PID decoupling control](image2)

![Figure 6. Temperature curve of tower top based on conventional decoupling control](image3)

![Figure 7. Temperature curve of tower top based on ABC-PID decoupling control](image4)

It can be seen from the figure 5~8, that the PID controller optimized by the algorithm has made the overshoot of the response curve better improved. When disturbance is added to the set value of the top of the tower at 200s, the curve rising process optimized by the algorithm is smoother, and the influence on the temperature of the bottom of the tower is smaller. When random disturbance is
applied in the process 400s, 500s, the overshoot is lower, and the influence on the top or bottom of the tower is smaller. The system is more stable.

5. Conclusion
Artificial bee colony algorithm is a new swarm intelligence algorithm, but it has been widely used in many fields. In this paper, the basic principle of artificial bee colony algorithm is summarized, and the parameter tuning of the PID controller based on ABC algorithm is analyzed. Finally, the application of the PID control technology based on artificial bee colony algorithm in the temperature decoupling control system of distillation column is applied. Through simulation analysis, the application of artificial bee colony optimization PID parameter method in the temperature decoupling control system of distillation column is reasonable.

References
[1] Feng Jing, Shuning. Theory and Application of Swarm Intelligence [J]. Computer Engineering and Application, 2006 (17): 31-34.
[2] Wang Zaiying, Liu Huaixia, Chen Yijing. Process Control Systems and Instruments [M]. 2013. P248-250.
[3] Wang Yan jiao. Research and Application of Artificial Bee Colony Algorithms Erbin University of Engineering, 2013.
[4] KARABOGA, D, Basturk, B. On the performance of artificial bee colony (ABC) algorithm [J]. Applied Soft Computing, 2008,8 (1) :687-697.
[5] Yu Lijun, Chen Jia, Liu Fanming, etc. Neural Network Decoupling Control based on PID of improved particle swarm optimization [J]. Journal of Intelligent Systems, 2015 (5): 1-6.