Research on PID Parameter Tuning Based on Improved Artificial Bee Colony Algorithm

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Abstract. Aiming at the difficulty of tuning industrial PID control parameters, an improved artificial bee colony PID tuning method is proposed. The improved artificial bee colony algorithm (IABC) uses Boltzmann selection mechanism to avoid premature convergence of roulette mechanism; at the same time, the global crossover mechanism is introduced in the domain search, which enhances the direction of the algorithm; and through chaotic avoiding search, the diversity of population is increased and the ability of global search is improved. Finally, the IABC algorithm is applied to PID parameter optimization of second order system. The simulation results show that the IABC algorithm obtains smaller ITAE and adjustment time than the basic artificial bee colony algorithm and Ziegler-Nichols engineering tuning method, and there is no overshoot. The performance of IABC algorithm is obviously improved.

Keywords: Artificial Bee Colony Algorithm, PID parameter tuning, Boltzmann selection, Global crossover, Chaotic avoiding search.

1. Introduction

PID parameter tuning is a difficult problem in industrial control, which usually includes theoretical calculation and engineering tuning. Among them, the theoretical calculation method relies too much on the mathematical model of the system, which requires a full grasp of the system mechanism. However, the engineering setting method is mainly based on the engineering experience, so it has great trial and error. In recent years, artificial bee colony (ABC) algorithm has been widely used in PID parameters. Cai Chao [2] and others used ABC algorithm to adjust PID parameters to improve the dynamic performance, rapidity and stability of the control system. Zhou Huaxiang [3] proposed immune bee colony algorithm, which could dynamically fit the diversity of the population and the convergence speed, so as to avoid the algorithm falling into local minimum. Zhang Dongli [4] and others used the improved artificial bee colony algorithm to design the AVR system with optimal fractional order PID controller, and achieved good results. However, as a new algorithm, ABC algorithm model is not very mature, there are still some problems such as easy to fall into local minimum point, as well as low convergence precision and slow convergence speed. In this paper, the IABC algorithm, which introduces Boltzmann selection mechanism, avoids premature phenomenon, and performs global crossover operation in domain search, which can effectively guide the search to converge to the optimal result and accelerate the convergence speed. Chaos avoiding search is used to improve the global searching ability. The application of IABC algorithm in PID parameter tuning makes the system obtain better control performance and provides theoretical basis for engineering application.
2. Basic Artificial Bee Colony Algorithm

In 2005, Turkish scholar Karaboga proposed artificial bee colony algorithm (ABC) [5] on the basis of previous studies, and applied it to the optimization of function extremum, and the result is very good. Later, the algorithm and its improved algorithm have been widely used in image processing, job scheduling, combinatorial optimization [6], path planning, traveling salesman, and other engineering fields. ABC algorithm is a kind of swarm intelligence model, through the cooperative cooperation among bee collecting, observation bee and reconnaissance bee to complete target search [7]. There are three stages in ABC algorithm: in the first stage, the honeybee searches in the food source field according to formula (1) and shares the food source information with the observation bee; in the second stage, the observation bee chooses a food source according to the probability formula (2) according to the honey source richness analyzed by the bees, and searches for a new honey source near the honey source; in the third stage, when the honey source is exhausted, the collecting bee becomes a reconnaissance bee, and presses Formula (3) generates new honey source by random initialization. Through the cycle of these three stages, new and better nectar sources are constantly found, and then the optimal nectar source is found. The field search of bee collection and observation is as follows:

\[ v_i^j = x_i^j + \alpha (x_i^j - x_k^j) \quad k \neq i \]  

(1)

Where \( i = 1, 2, 3 \ldots N, N \) is the number of nectar sources, \( j \) is the value of \{1, 2, ..., \( D \)\}, \( D \) is the number of position components of honey source, and \( \alpha \) is the random number between \([0, 1]\).

\[ p_i = \frac{f_{it}}{\sum_{n=1}^{N} f_{nt}} \]  

(2)

In formula (2), \( f_{it} \) is the fitness function value corresponding to the \( i \)-th solution, and \( p_i \) is the probability of the observation bee to select the \( i \)-th honey source.

\[ v_i^j = x_{\text{min}}^j + \alpha (x_{\text{max}}^j - x_{\text{min}}^j) \]  

(3)

In formula (3), \( x_{\text{max}} \) and \( x_{\text{min}} \) are the maximum and minimum of \( X \), and \( \alpha \) is the random number between \([0, 1]\).

3. Improved Artificial Bee Colony Algorithm (IABC)

A. Global cross domain search mechanism in ABC algorithm

Bees and observation bees are used for domain search according to formula (1), which shows that the algorithm is good at exploring and neglecting development. In order to enhance the development ability of the algorithm, Zhu\[8\] and others introduced the global optimal solution to guide the direction of the algorithm, as shown in equation (4).

\[ v_i^j = x_i^j + \alpha (x_i^j - x_k^j) + \beta (x_g^j - x_i^j) \quad k \neq i \]  

(4)

In formula (4), \( \beta \) value is used to balance the algorithm’s development and exploration ability, but this reduces the global optimization ability of the algorithm to some extent. In this paper, cross operation is used to improve the global optimization ability of the algorithm, that is to let the bees and observation bees conduct cross operation with the global optimization after the field search. However, only crossing with the global optimum will reduce the search ability. Therefore, the search ability can be enhanced by adding the \( \beta \) term to prevent the over development phenomenon of simple crossover with global optimal, as shown in formula (5).

\[ v_i^j_{\text{new}} = \begin{cases} v_i^j, & r \text{and} < cr \\ x_g^j + \beta (x_g^j - v_i^j) & \text{others} \end{cases} \]  

(5)

\( cr \) is the cross probability and \( x_g \) is the global optimal solution.

B. Boltzmann selection mechanism
If the observation bee chooses honey source according to the formula (2), the population diversity will decrease and the algorithm will converge prematurely. Therefore, the Boltzmann selection mechanism is introduced to adjust the selection pressure dynamically. In the early stage, the selection pressure is small, so that the poor individuals can survive and enhance the population diversity. In the later stage, the selection pressure is automatically increased to narrow the search range and accelerate the convergence speed of the optimal solution. The selection probability of food source selection of observation bee is as follows: formula (6):

\[ p_i = \frac{\exp(fit_i/T)}{\sum_{n=1}^{N}\exp(fit_i/T)} \quad T = T_0(0.99^c^{-1}) \]  

(6)

Where \( T_0 \) is the initial temperature and \( T \) is the variable temperature, \( c \) is the number of cycles.

C. Chaos avoiding search

ABC algorithm is used to search the field randomly, which is blind to some extent. It can not inherit the good gene evolution of the original local optimal solution, and there may be repeated search phenomenon. Due to the ergodicity of chaotic search, the diversity and search precision of the population can be effectively improved [9]. Therefore, by introducing the interference of turbid sequence, the candidate solution set is constructed near the current local solution, and the Scout bee selects the solution with the highest fitness among the candidate solutions to become a new honey source, which can not only effectively spring forth of the local extremum, but also inherit the good genes in the original local extremum to speed up the algorithm. At the same time, the memory function of avoiding table is used to record the local optimal solution that has been searched. If the solution is encountered next time, it will be skipped to avoid falling into local minimum, thus increasing the diversity of solutions. Specific update rules: if the food source still has no update after continuous limit times, it will be liberated into the avoiding list, and then according to formula (8), a chaotic sequence candidate solution is generated near the local solution, and the better candidate solution that is not in the avoiding table is selected as the new honey source. If all the candidate solutions are in the avoiding table, the new solution will be generated randomly. The chaotic sequence \( Y_i \) is generated by tent mapping, and then mapped to the solution space \([x_{\text{min}}, x_{\text{max}}]\), then the chaotic vector is constructed as follows:

\[ Y_i = x_{\text{min}} + y_i \times (x_{\text{max}} - x_{\text{min}}) \]  

(7)

The original local solution \( x \) is perturbed individually to generate the candidate solution. \( \text{new}X_i \) is:

\[ \text{new}X_i = (X + Y_i)/2 \]  

(8)

\[ d(\text{new}X_i, tX_k) = \|\text{new}X_i - tX_k\| \]  

(9)

The Euclidean distance between the candidate solution and the elements in the avoiding table is calculated by equation (9). If it is less than the set threshold, the solution is in the avoiding table. \( tX_k \) is the \( k \)-th element of avoiding list.

D. IABC algorithm combines Boltzmann selection

Global cross domain search and avoiding search to form an improved bee colony algorithm (IABC). The specific the flow of IABC algorithm is shown in Figure 1.
4. Case Study

A. IABC_ PID control principle in the IABC algorithm

The PID controller $K_p$, $K_i$, $K_d$ to be optimized parameters as honey source, with a certain performance index as the objective function, to form a new type of IABC_ PID optimization algorithm. The core problem of the algorithm is to find a group of $K_p$, $K_i$, $K_d$ parameters by using artificial bee colony algorithm, so that a certain performance index of the system can reach the minimum value, and the controlled quantity can quickly reach the expected target, and there are ultra-small overshoot and small adjustment time.

The second order system is selected as the controlled object, and its transfer function is as follows:

$$G(s) = \frac{2}{s^2 + 2.6s + 1.6}$$  \hspace{1cm} (10)

B. Fitness function

Because the system's absolute error moment error (ITAE) performance index formula (11) has good practicability and selectivity [10], so ITAE is selected as the objective function. The fitness function is inversely proportional to ITAE, as shown in equation (12), that is, the smaller the performance index ITAE, the higher the fitness, the better quality of honey source.

$$\text{ITAE} = \int_0^\infty t |e(t)| dt$$  \hspace{1cm} (11)

$$fit_i = \frac{1}{1 + \text{ITAE}_i}$$  \hspace{1cm} (12)

C. IABC_ PID algorithm setting steps

The basic steps of PID algorithm tuning are as follows:

Step 1: Initialization, determine the number of population, the maximum number of iterations maxcycle, search limit, crossover probability $C_r$, the range of control parameters $K_p$, $K_i$, $K_d$ etc.

Step 2: The NP group $K_p$, $K_i$, $K_d$ feasible solutions (honey source) are generated randomly. The output response of the controlled object after PID control is obtained, and the fitness is calculated. The first 50% optimal solution is taken as the honeybee.
Step 3: Each bee collected honey in the vicinity of the original honey source for global cross, looking for new honey source, and according to the greed criterion to select honey sources.
Step 4: According to Boltzmann mechanism, the probability of honey source being followed is calculated.
Step 5: The observation bees searched in a global crossover mode and retained better nectar sources.
Step 6: If a honey source has been searched for a limited number of times and has not been updated, the honey source will be forsaken, and the honeybee will be transformed into a reconnaissance bee, and a new honey source will be generated through chaotic avoiding search.
Step 7: Determine whether the maximum number of iterations MaxCycle is reached, no, jump to step 3. Yes, the algorithm is done.

5. Simulation Experiment and Result Analysis
In the simulation experiment and result analysis, three methods, Ziegler-Nichols engineering tuning method, ABC algorithm and IABC algorithm, are selected to adjust the PID parameters of the controlled object in equation (10), and the experiment is carried out on the MATLAB(Fixed-step, ode3). The unit step response is shown in Figure 3. Among them, the parameters of the two bee colony algorithms are: $K_p$ is [0, 200], $K_i$ is [0, 20], $K_d$ is [0, 50], the number of population is 40, the maximum number of iterations is 100, the number of search times is 10.
The unit step response curves are shown as in figure 2.

![](image)

**Figure 2. Unit Step Response Curve.**

The setting results of the three algorithms are shown in Table 1.

| Algorithm          | ITAE  | ts/s | σ/%  | PID parameter  |
|--------------------|-------|------|------|----------------|
| Ziegler Nichols    | 0.2156| 1.68 | 23.37| Kp 12, Ki 5, Kd 0.96 |
| ABC                | 0.0238| 0.42 | 3.52 | Kp 75.6084, Ki 0.3617, Kd 7.1678 |
| IABC               | 0.0224| 0.22 | 0.51 | Kp 118.8653, Ki 0.257, Kd 10.7218 |

Table 1 and figure 2 state that the operation effect of IABC algorithm is significantly improved, and the ITAE value is smaller, the adjustment time is less, and there is almost no overshoot.
The optimization process of two bee colony algorithms is shown in Figure 3. It can be concluded from the figure that the IABC algorithm converges rapidly after 20 iterations, which shows that it has efficient search ability and fast convergence speed.
6. Conclusion

The IABC algorithm adopts Boltzmann selection mechanism to increase population diversity at the early stage of the algorithm, effectively avoids premature convergence, and introduces global crossover operation, which can effectively guide the search to converge to the optimal solution; and the algorithm uses chaotic avoiding search to improve the global searching ability. The algorithm has strong search ability and development ability, and improves the convergence accuracy and convergence speed of the original ABC algorithm. IABC_PID controller optimized by PID algorithm has no overshoot, fast response and small ITAE, The algorithm has a good prospect of engineering application. Due to the article space, the reliability of the algorithm needs to be further verified.

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