Improving the application of fuzzy RBF neural network in temperature control system

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Abstract. The temperature control system of aircraft ground air conditioning has the characteristics of complex work, non-linearity and time-varying working, the traditional PID control overshoot is too large and the response speed is low, which can not meet the needs of high efficiency and speed. In order to improve the control performance of aircraft ground air conditioning, a fuzzy RBF neural network optimized by the improved bacterial foraging (BFO) and flower pollination (PFA) algorithm was designed, and the air conditioning system was modeled and simulated. The analysis results show that the improved algorithm has better control ability than other algorithms in terms of control accuracy and anti-interference ability, effectively restraining the large lag and other problems, which provides a theoretical reference for the optimization of air conditioning temperature control system.

1. Introduction

Aircraft ground air-conditioning is the equipment that provides the required air in the cabin of the aircraft when the engine of the aircraft has stopped working and the aircraft equipment needs to be repaired[1]. In the past, when aircraft were docked on the ground, they relied on their own auxiliary power unit (APU), a high-energy-consuming and high-polluting device to supply air. Under the slogan of the State Council "Winning the Defense of the Blue Sky", relevant parties require that major airports must construct and vigorously promote new energy equipment. Under this call, Guangzhou Baiyun Airport required major airlines to use aircraft ground air-conditioning of airport operation equipment to provide air-conditioning and cooling services for boarding bridges and aircraft. With the increasing demand for ground equipment, some problems of aircraft ground air conditioning have gradually been exposed. For example, the cooling is not fast enough, and the temperature variation control is not stable enough.

The temperature control system determines the quality of the air conditioning system. The temperature controller adjusts the hot and cold valves of the air conditioner by a given control signal, and changes the air supply to achieve real-time temperature adjustment. At present, PID control is the most widely used in temperature control. A large number of industrial production activities prove that PID control has a simple structure and strong robustness, which is suitable for application to aircraft ground air-conditioning temperature control systems. However, with the development of the civil aviation industry, under the different environmental and temperature conditions, aircraft ground air conditioners have become increasingly prominent in non-linear, time-varying, and many interference signals, and traditional PID control appears to be inadequate. With the development of intelligence theory and algorithms, the latest research results have been incorporated into the PID tuning. For example, in reference [2], a hybrid frog jumping algorithm (SFLA) that introduces mutation
ideas is used to accelerate the algorithm's convergence speed, thereby optimizing the PID. Reference[3] relied on improved pollination algorithm and applied it to PID control, using the characteristics of pollen cross-pollination to solve the problem of slow convergence in the later period. According to the characteristics of the aircraft ground air-conditioning temperature control system, an optimized pollination algorithm for bacterial foraging was designed to optimize the parameters of the fuzzy RBF neural network, and PID control was optimized to realize the aircraft ground air-conditioning control.

2. Establishment of temperature control system model

At present, there are three main types of aircraft ground air conditioners used in the civil aviation industry. One is hoisting below the boarding bridge corridor, the second is directly landing on the ground near the boarding bridge corridor, and the third is mobile aircraft ground air conditioning. Guangzhou Baiyun Airport adopts the first method, as shown in the following figure:

![Figure 1 Ground Air Conditioning for Ceiling Aircraft](image)

Energy conservation equation of aircraft ground air-conditioning control system\[4\]:

\[
Cv \cdot V \frac{dt}{d\tau} = \rho \cdot c \cdot G(t_s - t) - \frac{t - t_0}{R}
\]

(1)

Where G is the air supply volume and R is the enclosure.

After finishing the above formula, the transfer function is obtained as:

\[
G(s) = \frac{K}{Ts + 1}
\]

(2)

Where \( K = \frac{G \rho c}{G \rho c + \frac{1}{R}} \) is the gain coefficient and \( T = \frac{Cv \cdot V}{G \rho c + R} \) is the inertia time constant.

According to the data and temperature control logic, the controller needs to monitor the temperature of the return air and the valve opening in real time. Taking into account factors such as different regional locations, different environmental conditions, and climatic differences, air-conditioning equipment must meet the temperature and other ventilation conditions required by the environment. Based on various factors and mathematical derivation, the temperature control model is:

\[
G(s) = \frac{1}{150s + 1} e^{-20s}
\]

(3)

3. PID control of fuzzy RBF neural network

3.1. Temperature PID control of aircraft ground air conditioner

PID control is a typical control system in field industrial production. The temperature control system of the aircraft ground air conditioner is similar to the general temperature control. Most of the temperature control at home and abroad mainly adopts PID control. In its temperature control system, set temperature \( r(t) \) and on-site measured temperature \( y(t) \) are important parameter indicators, which not only control the operating frequency of fans and water valves, but their deviations are also used as error function indicators and applied to PID control. The difference is The formula is\[5\]:

\[\text{error} = r(t) - y(t)\]

The deviation is the difference between the set temperature and the measured temperature, which is used as an error indicator in the PID control system.
3.2. PID control of fuzzy RBF neural network

The fuzzy RBF neural network PID controller consists of a PID control part and a fuzzy neural network[6]. In the designed temperature control system, the error and its rate of change are used as the input of the controller, and the three parameters of PID are used as the output. The network level and input and output variables of the controller are shown in Figure[7]:

![Figure 2 PID structure diagram of fuzzy RBF neural network](image)

The first layer is the input layer of the system. The input and output of the nodes of this layer are expressed as:

$$f_i(i) = [e, \Delta e]$$  \(\text{(5)}\)

The second layer is the fuzzification layer, which uses the Gaussian function as the membership function[8]. For the first node:

$$f_2(i, j) = \exp(\text{net}_j^2)$$  \(\text{(6)}\)

$$\text{net}_j^2 = -\frac{(f_i(i) - c_d)^2}{(b_j)^2}$$  \(\text{(7)}\)

The third layer uses fuzzy reasoning to complete the rule matching with the previous layer, and each node uses the product calculation of the signal to obtain its output:

$$f_3(j) = \prod_{i=1}^{N} f_2(i, j)$$  \(\text{(8)}\)

The fourth layer is the output layer, whose output is the sum of the weights of all inputs, that is:

$$f_4(l) = w \cdot f_3 = \sum_{j=1}^{N} w(l, j) \cdot f_3(j)$$  \(\text{(9)}\)

4. Fuzzy RBF neural network with BFO optimized

4.1. Flower pollination algorithm

Flower pollination algorithm

The flower pollination algorithm is inspired by the process of pollination of flowers, and some optimization problems are calculated by simulating the behavior of flower pollination. The global optimization (pollination) method is based on the characteristics of the pollinator Levi flying, so it occurs in a relatively random area. Local pollination is spreading on its own flowers. Assume that each solution in our optimization process corresponds to each pollen, and the position update formula of pollen is obtained[9]:

$$x_n = x_h + L(x_h - p_n)$$  \(\text{(10)}\)
Where \( x_i \) is the position of the individual and \( p_{gi} \) is the global optimal solution.

In formula(10), \( L \) obey the \( \text{Levy} \) distribution, which satisfies the distribution\(^{[10]}\):

\[
L \sim \text{Gam}(\gamma) \ast \sin(\pi \gamma / 2) / \pi s^{1 + \gamma}
\] (11)

Because the algorithm can quickly converge to the characteristics of all regions of the optimal solution, the flower pollination algorithm has been widely used by scientists to optimize nonlinear functions and some neural network optimization processes.

### 4.2 BFO optimized pollination algorithm

Based on the FPA algorithm, a bacterial foraging algorithm is designed to use its migration, replication, and chemotaxis algorithm ideas to solve the situation that the original algorithm is prone to precocity and sometimes falls into a local optimum. Optimize the FPA algorithm\(^{[11]}\).

The specific steps are:
1) First calculate the fitness value using the FPA algorithm;
2) Perform migration, copy, and chemotaxis on the obtained fitness value; retain the optimal fitness value;
3) Determine whether the conditions are met, if not, return 1).

Chemotactic. Generate a random direction \( \Delta(i) \) and randomly adjust the direction to get a new fitness value.

\[
x_{is} = x_{is} + c(i) \ast v(i)
\]

\[
v(i) = \frac{\Delta(i)}{\sqrt{\Delta^T(i) \ast \Delta(i)}}
\] (12)

Where \( c(i) \) is the step size of the bacteria after changing the azimuth, and \( v(i) \) is the random azimuth vector that is flipped.

Copy. The first \( Sr \) populations in descending order are selected and then reproduced. Enhance global search capabilities. In both processes, the step size is constantly changing.

\[
c(i) = c_{min} + (c_{max} - c_{min}) \ast \text{rand}
\] (13)

### 4.3 Fuzzy RBF neural network based on improved FPA

In the fuzzy RBF neural network algorithm, the initial values of the parameters \( w, c, \) and \( b \) are random. In most cases, they are manually tried or continuously adopted random numbers. Whether these parameters are selected properly determines the algorithm directly High and low accuracy and excellent network performance. Therefore, the design uses an improved algorithm instead of calculating the values of various parameters.

According to the network characteristics, ITAE is adopted as the evaluation index of the fitness function.

\[
J = 100 \sum_{i=1}^{N} |e(i)|
\] (14)

According to the characteristics and structural characteristics of the PID, the selected RBF network structure is a structure of 2-25-25-3. The learning rate of the neural network is \( \alpha = 0.2 \), and the momentum factor \( \beta = 0.05 \). The expression of the optimization parameter \( \mathbf{P} \) required by the designed neural network is:

\[
\mathbf{P} = [b_1 \ b_2 \ \cdots \ c_{11} \ c_{12} \cdots w_1 \ w_2 \cdots]
\] (15)

### 5. Cascade PID control of fuzzy RBF neural network with improved FPA algorithm

#### 5.1 Cascade Temperature Control System

Because the aircraft ground air conditioner has too much external interference, a single control link cannot meet the demand, so the combination of air volume control and temperature...
control is used to form a cascade PID control. Compared with a single control link, its structure forms two closed loops. After improvement, the schematic diagram is as follows:

![Schematic diagram of temperature control system based on improved algorithm](image)

Figure 3 Structure of temperature control system based on improved algorithm

In the entire temperature control system, the secondary loop air volume controller adjusts the size through a valve and selects P control. The main loop temperature controller needs to maintain the requirements of the temperature control system to achieve precise control, so PID control is required.

5.2 Improved FPA's fuzzy RBF algorithm flow

1) Initialize each pollen unit and randomly generate the initial optimal solution;
2) Calculate the fitness value of the network parameters \( w, b, \) and \( c \) as the solution target;
3) Let the pollination algorithm calculate the optimal solution first;
4) Update the optimal solution through the BFO migration, replication, and chemotaxis process;
5) Exit if the conditions are met, otherwise return 2).

5.3 Simulation results

According to the designed algorithm, the algorithm is simulated, the number of chemotaxis is 50, the probability of bacterial dispersal is 0.25, and compared with other intelligent algorithms, the fitness function comparison curve is obtained as

![Fitness value characteristic curve](image)

Figure 4 Fitness value characteristic curve

The optimal value of the fitness function of the improved FPA algorithm is obtained by simulation: \( J_{\text{best}} = 42.8781 \).

From the curve and the data, it can be clearly compared that the improved FPA algorithm obtains the optimal solution through iteration. The parameter values of the obtained fuzzy RBF neural network are brought into it, and the corresponding simulation is performed according to the condition that the ground air conditioner of the aircraft needs to meet the 10°C cold wind.
Figure 5 Comprehensive comparison of response output curves

Table 1 Control performance comparison of air conditioner temperature PID controller

| CONTROL TYPE | tr  | ts  | δ    |
|--------------|-----|-----|------|
| BFO-FPA      | 132 | 198 | 3.5% |
| Z-N          | 80  | 302 | 28%  |

It can be seen that the improved PID control curve at about 200s has reached the stable state of 10℃ set by the air conditioner, while the traditional PID control has a large overshoot and significant oscillation, which can no longer meet the needs of an overly complex and variable working environment. Although many algorithms can play a role in PID control, the effect is not improved. FPA algorithm is obvious.

In addition, in order to verify the control performance of the improved algorithm, at 500s, a random signal interference was added to the control system. It can be seen that the improved RBF control system quickly returns to a stable state after being disturbed. Therefore, the improved algorithm has its own unique advantages in all aspects of the control system, effectively solving the problems of non-linearity and time variation of the aircraft ground air-conditioning system, and meeting faster and more accurate design requirements.

6. Conclusion

In order to solve the problems of the aircraft ground air-conditioning temperature control system, an improved fuzzy RBF neural network PID controller designed by BFO is designed, which searches in parallel based on the BFO algorithm, has the ability to jump out of the characteristics of the local optimal solution, and improves the global search of the FPA algorithm. The improved algorithm was used to optimize the fuzzy RBF neural network, which was applied to the aircraft ground air-conditioning temperature control system. According to the requirements of environmental climate and temperature, algorithm simulation was performed to obtain the fitness and response output curve of the modified algorithm, and compared with several other algorithms. The simulation results prove that the improved algorithm has faster response speed, stronger robustness and stability than PID algorithm. Its temperature control system is optimized to make it better applied to aircraft ground air-conditioning control systems, which has broad prospects and development trends.

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