Design of Room Temperature Control System for Inverter Air Conditioner
Based on Fuzzy Neural Network

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Abstract. With the progress of science and technology and the demand of people for material life, smart home appliances have become an inevitable trend of the development of household appliances in the future. In the face of widely used inverter air conditioner and its fast temperature regulation demand for closed indoor environment, the design of fuzzy neural network controller with inverter air conditioner is designed on the basis of setting up the transfer function model of indoor temperature and environment, which is compared with traditional PID and its fuzzy control by simulation and verification. The speed and stability of adjusting the temperature of closed indoor rooms have achieved better results.

Foreword

It is required that the comfort of the air conditioner is more and more comfortable for the room temperature control, not only the control of the air conditioner can’t be cold and hot, but also it can’t have a larger overshoot of temperature. For the inverter air conditioner, the air conditioner manufacturer does not allow the temperature to have overshoot. This is not only to improve the comfort of temperature control, but also to increase the energy efficiency ratio of air conditioners and make the air conditioners more energy efficient. For the adjustment time of the control, the air conditioner manufacturers to adjust time is greater than or equal to the control room air equivalent coefficient of the first-order inertia link and temperature control of the delay time of the sum of the time factor, and less than or equal to 4 times of the sum of the time[1]. Because of this large inertia and pure delay system, it is difficult to achieve no overshoot in traditional PID control. Therefore, this paper gives a temperature control system based on fuzzy neural network algorithm, which adjusts the temperature of the room and the working frequency of the air conditioner, realizes the room temperature control without overshoot, reduces the energy consumption of the air conditioner and improves the reliability and life of the frequency conversion air conditioner.

Establishment of Mathematical Model for Temperature Control of Indoor Air Conditioner System

In order to make the transfer function of indoor air easy to deal with and better stability, the temperature control system of indoor frequency conversion air conditioner is simplified as a first order inertial link and a delay link[2]. The smaller inertia coefficient of the metal parts of the air conditioner is added to the larger inertia coefficient of the indoor air to form a first order inertia ring. The transfer coefficient of the inertial ring is K1. The equivalent formula of the first order inertial link is as follows:
\[ G_1(s) = \frac{U_c(s)}{U_i(s)} = K1/(TS+1) \]  

(1)

Where \( T \) is the inertial coefficient of the first order inertial ring. Because air is blown out of the air conditioner, it needs to circulate in the room for a week before it can be detected by the room temperature probe in the air conditioner, so there is a delay. The existing delay ring e-dodge \( s \) was substituted into the equation (1) to obtain the following formula:

\[ G_2(s) = K1e^{-\tau s}/(TS+1) \]  

(2)

In the simulation experiment, 1.5 hours power of kfr-35gw /Bp cold and warm inverter air conditioners were selected. The laboratory is a room with a length of 10 meters, a width of 5 meters and a height of 3 meters. Known air parameters \( \rho=1.225\text{kg/m}^3 \), \( c=1.005 \text{kJ/kg·}^\circ\text{C} \), by equation \( T=\frac{m}{Q_m} = \frac{\rho vt}{\rho v'} \), calculate \( T=360 \), transfer coefficient \( K1 \) is 1.2[3]. The delay time of the measured temperature detection is 20 seconds, and the coefficient is substituted into equation (2) to obtain the required temperature transfer function:

\[ G_3(s) = 1.2e^{-20s}/(360S+1) \]  

(3)

Design of FNNC for Inverter Air Conditioner

Fuzzy Radial Basis Function Network Construction

RBF neural network has the advantages of local convergence and fast processing speed. BP neural network for the global convergence, and the layer number is more, although it can approximate any nonlinear function, but every sample learning to readjust the ownership of the value network, result in slow convergence speed, easy to fall into local minimum, it is difficult to meet the requirements of high real-time control system[4]. The temperature control range of this project is 18~32 degrees, and the control environment is indoor limited environment. Therefore, RBF neural network is applicable to the study of this project. At the same time, the fuzzy RBF neural network algorithm can make the control system have the real time of fast calculation and processing.

Figure 3-1. Structure diagram of RBF neural network fuzzy system.

Figure 3-1 shows the fuzzy RBF neural network structure which consists of four layers. The first layer is the input layer, and the input signal \( X_1, X_2 \) is represented by the following formula:

\[ X_1 = e(t), X_2 = \Delta e(t) = [e(t) - e(t-T)]/T \]  

(4)

In the fourth formula, \( e(t) \) is the temperature deviation, and \( \Delta e(t) \) is the deviation rate. Each node of the input layer is directly linked to each component of the input quantity. The weight of the link \( W=1 \) is then transmitted to the next layer. The second and third layers are the fuzzy layer. Gaussian function is used as the membership function to fuzzy the input variables \( X_1 \) and \( X_2 \). The fuzzy treatment formula is as follows:

\[ Y(i,j) = \exp\left[-(X_i-C_{ij})^2/2(B_j)^2\right] \]  

(5)

In the fifth formula, \( C_{ij} \) and \( B_j \) are the mean and standard deviation of the membership functions of the \( J_{th} \) fuzzy set of the \( I_{th} \) input variable. After each variable is blurred, it is denoted by \( P, Z \) and \( N \),
which means positive, zero and negative three general states. The fourth to fifth layers are the control layer, and the fourth layer is the "and" neuron layer of the fuzzy reasoning layer, and the weight value of the connection is 1. The fifth layer is the "or" layer of neurons in the fuzzy reasoning layer. Four or five layers work together to advance the rules, and each node in this layer corresponds to a rule. Each output node j at this layer is the product of all input signals at that node. It can be described by the rule which is Rᵢ: if(X₁=Nᵢ₁) or(X₂=Nᵢ₂) then(u=Tᵢ). In this rule, Nᵢ₁ = [NB, NM, NS, ZO, PS, PM, PB]; Nᵢ₂ = [NB, NM, NS, ZO, PS, PM, PB]; And Tᵢ = [NB, NM, NS, ZO, PS, PM, PB]. In this layer, the matching of fuzzy rules is completed through the connection between this layer and the fuzzy layer, and the fuzzy operation is completed between nodes. The sixth layer is the output layer, which realizes the inference between rule premise and conclusion and the inference between rules[4]. This layer also can be called a defuzzification process, used to produce the total output of control rules. The output formula is as follows:

$$F = \sum_{i=1}^{N} \omega(i,j) \cdot [\prod_{j=1}^{n} Y(i,j)]$$  \hspace{1cm} (6)

In equation (6), N represents the number of nodes in the output layer, while axial is the connection weight matrix between nodes in the output layer and each node in the fuzzy inference layer. Where N = \prod_{i=1}^{n} Nᵢ. Nᵢ as the input layer of the ith the number of input membership functions, it also blurred layer node number. The parameters w and function Y (I, j) in formula (6) can continuously optimize the performance of the controller through the self-learning of the neural network. The objective function of fuzzy RBF neural network is defined as:

$$E(t) = \frac{1}{2} \sum_{i=1}^{L} (f(k) - f_m(k))^2$$ \hspace{1cm} (7)

The f(k) in formula (7) is the actual output, while fₘ(k) is the network output. On the basis of formula (7), the weight learning algorithm formula of output layer can be derived[4]:

$$\omega(k) = \omega(k-1) - \eta \cdot \frac{\partial E}{\partial \omega} \cdot \frac{\partial u_m}{\partial \omega} + \delta(\omega(k-1) - \omega(k-2))$$ \hspace{1cm} (8)

The final weight learning algorithm formula was obtained by simplifying formula (8):

$$\omega(k) = \omega(k-1) - \eta \cdot \{f(k) - f_m(k)\} \cdot [\prod_{j=1}^{n} \exp(- \frac{(x_i - c_j)^2}{2(\sigma_j)^2})] + \delta(\omega(k-1) - \omega(k-2))$$ \hspace{1cm} (9)

The information in formula (9), the \( \eta \) is the learning rate and the \( \delta \) is a momentum factor. By referring to the data[4], it can be obtained that the value range of the coefficient should be greater than zero and less than one. So in the end, the learning rate is \( \eta = 0.45 \), and the momentum factor is \( \delta = 0.2 \).

The Establishment of Simulation Model

The fuzzy neural network control program consists of the training part of the network and the control part of the network. The network training part includes data import of training samples, membership function import of fuzzy neural network, and training self-learning within a specified time. Firstly, according to equations (7) and (9), the weights are learned and adjusted by network training, so that indoor temperature and control signal have a good correspondence. Then the trained weights are assigned to the neural network, so that the control program has a good grasp of room temperature. Finally, the rate of change of temperature deviation and temperature deviation is amplified and preprocessed[5]. In MATLAB, the fuzzy neural network toolbox is used to carry out the network training part of fuzzy neural network. Among them, the input and output variables are as follows:

- e=[-4°C, +4°C] ec=[-0.5°C, +0.5°C] f=[10Hz, 80Hz]
Because people for greater than ±1°C temperature had obvious feeling, in order to ensure the comfort, therefore ec values in [-0.5 °C, +0.5 °C]. After learning and training, the membership function curve of fuzzy control rules is automatically adjusted, as shown in Figure 3-2.

![Figure 3-2. Fuzzy membership function curve and fuzzy inference output characteristic surface after learning.](image1)

According to the first graph in Figure 3-2, it can be found that the curve of the membership function is uniformly distributed on the coordinate axis, and the curve waveform of the function is relatively smooth, its control characteristics are relatively mild, and the system stability is relatively good. Finally, the characteristic surface of fuzzy inference output can be observed, as shown in the second picture of Figure 3-2. From the second picture in Figure 3-2, it can be seen that the control sensitivity of the system is high, the resolution is high, and the reaction speed is rapid and the stability is good.

The training results are imported into the working space of MATLAB. According to the above selected parameters and formulas, the simulation is carried out according to the control principle shown in Figure 3-3.

![Figure 3-3. Fuzzy neural network simulation model structure diagram.](image2)

The fuzzy RBF controller is a dual input and single output system. The output inverter power frequency can be used to adjust the speed of the refrigeration compressor to control the temperature of the air conditioner.

**Design of Fuzzy Neural Network Control Algorithm**

In the simulation, the fuzzy neural network tool kit is used to realize the learning and output of the fuzzy neural network according to the above models and parameters. Input signal is sensors detect the room temperature, the output data for fuzzy neural network control of the compressor frequency, after a certain number of learning, can make the output of the control system of approximation required value, will be at this time of each node weights in the form of files in MATLAB in the Workplace, during the actual control of temperature from the right to read the stored value in the Workplace, according to practical input FNNC can e and ec value to realize control of the system, Figure 3-4 for fuzzy neural network real-time control software design flow chart.
Experimental Simulation Results and Analysis

Set the room environment as the ideal state, delay time is 20S, the room of initial temperature of 0°C to 30°C heating simulation, and the simulation time is 1800S. The simulation results are shown in the first picture of 4-1.

As can be seen from the first picture in Figure 4-1, the PID system gradually stabilizes after 1200S, and the output overshoot is large. When the invalid power is generated, the electric opportunity heats up, which reduces the energy efficiency ratio of the air conditioner, and also affects the reliability and life of the inverter compressor and the inverter drive module[1]. This situation is not allowed in inverter air conditioner. The dotted line shows that, under the fuzzy control, room temperature is stable at around 600S. The fuzzy control performance is better than the pure PID control, which has been reduced by half and has achieved a steady temperature in both oscillating waves. Although the fuzzy control is better than the PID control, there is still overshoot.

Under the control of fuzzy neural network, the indoor temperature gradually reaches a steady state when it approaches 300S, and there is no overshoot and oscillation phenomenon in the heating process. The control effect is good, which fully meets the performance requirements of the inverter air conditioner.

Based on the simple thermal simulation experiment in the ideal environment of the first picture in Figure 4-1, a simulation experiment of refrigeration was conducted after heat production, to test whether the temperature rise and fall meet the control requirements. In the same working environment and a controller, in the case of delay of 20S, conditioner from 0°C to 30°C, the temperature stability after cooling to 24°C, the simulation time is 1800S. On the basis of the first test, the PID control parameters are adjusted to stabilize the speed faster. The fuzzy rules were also modified to slightly reduce the overshoot, but the disadvantage was that the work efficiency was reduced, and the room temperature could not be adjusted as fast as the first picture in Figure 4-1. As shown in the first picture of Figure 4-1, the thermal control effect of fuzzy neural network is the same as that the first picture in Figure 4-1. At more than 900S, the system detected that the indoor temperature tended to be stable and began to cool down, reaching the target temperature value within 300S without overshoot oscillation.
It can be seen that the performance of fuzzy neural network control system is superior to PID and fuzzy control system in all aspects.

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