ISSN : 0974 - 7435 Volume 10 Issue 12

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(12), 2014 [6246-6252]

Dual mode control research of variable air volume air conditioning system

Jiejia Li[1], Xiaoyu Sun[2]*

School of Information and Control Engineering, Shenyang Jianzhu University, Liaoning, 110168, (CHINA)

E-mail : 764327854@qq.com

ABSTRACT

On the basis of analyzing the local control of variable air volume (variable air volume, VAV) systems, puts forward the two kinds of real-time optimization control scheme. One is when the difference between actual room temperature and set temperature is small change the indoor air output to adjust the room temperature; the other is when the difference between actual room temperature and set temperature is big change indoor air output and supply air temperature to adjust the room temperature at the same time. And the combination of fuzzy neural network controller and neural network predictor can predict the new wind force for indoor online, it will reduce light running time of the air conditioning system. The results show that the system is under partial load cases, especially in smaller load using the method of combining two optimization scheme can not only save more energy, but also can improve indoor thermal comfort.

KEYWORDS

VAV air conditioning system; Real-time optimization control; Fuzzy neural network; Save energy; Improve indoor thermal comfort.

INTRODUCTION

VAV air conditioning system is a full air system, it controls the temperature in one area of the building of an air conditioning system by changing the supply air (also can adjust supply air temperature), the system can adjust the air conditioning air output automatically according to the requirements of the changing air conditioning load and indoor parameters, it could satisfy the requirement of indoor personnel comfort and save much of energy at the same time. Due to the characteristics of high efficiency, energy saving, easy to reorganization and expansion the research of the VAV air conditioning system has become a focus in research of intelligent building field.

However, because of the VAV air conditioning system has the characteristics of multiple variable, nonlinear, large delay and time-varying, the traditional control method has been unable to achieve good control effect. The method of multiple mode control sets up an air conditioning control system, which combines the control of air volume size, supply air temperature, air supply duct static pressure regulating. Through the central controller this method can selectively control different controlled object. And take advantage of the characteristics of neural network can be a very good approximation of nonlinear system. Establishing a reference model on-line, completing the dynamic characteristics of a system identification, improving the control effect.

THE WORKING PRINCIPLE OF VARIABLE AIR VOLUME AIR CONDITIONING SYSTEM

Variable air volume air conditioning system is mainly composed of four parts, for air handling and transportation equipment, duct system, automatic control system and VAV terminal device (VAV box). The working principle of VAV air conditioning system is: the air conditioning system calculates the collected data from the monitoring device, after comparing with the set value, it will calculate the opening of each end (terminal)of the air valve shoud be, through the terminal device, adjust the room temperature to the default values. So how to make the air conditioning system achieve the control goal fast and stable is the pivotal issue of whether the air conditioning system control performance is good or not. To meet people's requirement of air quality and energy saving effect we need to come up with a better control strategy.

THE STRUCTURE OF THE CONTROL SYSTEM DESIGN

By changing the air volume to the air conditioning room VAV air conditioning system adjust the indoor temperature to room temperature set point, compared with the constant air volume air conditioning system, most of time of the VAV air conditioning system is working under partial load and low load condition. However, when large amount of interference in the room, just by changing the delivery room temperature to achieve the set value, will make the regulating time of the system is too long, or increase the air volume input at the same time to improve the quickness of the air conditioning system reaching set temperature, this method can not only increase the energy consumption of the system, also can affect the indoor environment comfort badly. So, it is the most energy-efficient mode by adjusting the air volume size to adjust the room temperature reaches the temperature set point when the error between the actual temperature and set temperature within a certain range, however, when the error value beyond a certain range, just uses the adjustable air volume change to achieve the temperature set point will increase the system energy consumption, reduce the comfort of the room. So when the disturbance in the room is different using different control methods. The control system structure diagram is shown in Figure 1.

Two kinds of control mode are presented in this paper, the difference between them are different output and different control objects. But fuzzy controller 1 and fuzzy controller 2 have the same algorithm and input variable, the four inputs of the fuzzy neural network are the error e1 between the

room temperature set point and the actual temperature value, the error e2 between the neural network prediction output and room temperature set point, the error e4 of return air temperature and the air duct static pressure values. But the two output variables apply to different controlled objects, when the error e1 is greater than a certain range, changes the apply air volume and air supply temperature at the same time, means that the method of the fuzzy neural network controller output variables u1 of fuzzy neural network controller 1 is two-dimensional, controls the supply air duct heating device inside the motor and the air valve of the supply fan to adjust air valve respectively. When the error between the room temperature set point and the actual temperature does not exceed a certain range the system still adopts variable air volume adjustment method, namely, the output variables u2 of the fuzzy neural network controller 2 is one-dimensional, controls the air valve of the supply fan. As the room setting error e1 changes, choose different control method to realize the room temperature adjustment, reduce system energy consumption as well as improved the comfort of the room. Now set the critical value of e1 is E_k.

When the value of the error e1 is greater than E_k, the fuzzy neural network controller 1 was open, assuming this control method is model 1. When the error e1 value between 0 and E_k, the fuzzy neural network controller 2 was open, assuming this control method is model 2. When choosing different fuzzy neural network controller, the input u of predictor also changed accordingly, u is the output of the fuzzy neural network controller.

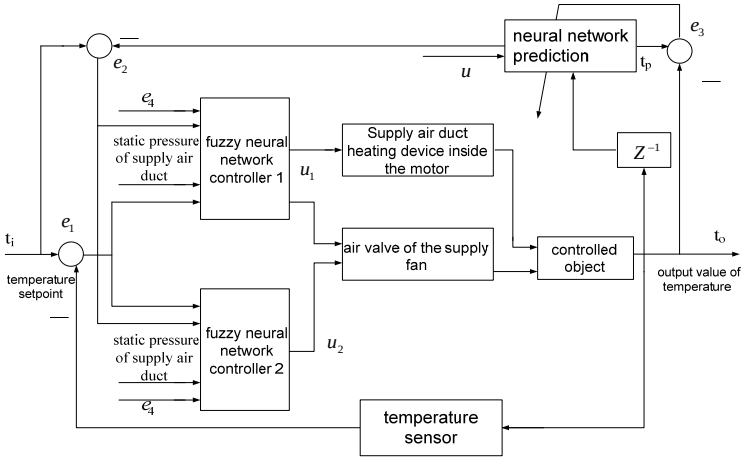

Figure 1 : The structure of the control system

THE DESIGN OF FUZZY NEURAL NETWORK CONTROLLER AND NEURAL NETWORK PREDICTOR

The Design of Fuzzy Neural Network Controller

This paper proposed the air conditioning system control part is composed of controller and predictor, the controller is composed of fuzzy neural network controller 1 and fuzzy neural network controller 2, they are parallel. By judging the system selects one of control modes and passes its output to the actuators. The fuzzy neural network controller structure is shown in Figure 2. There are four layers in the fuzzy neural network, they are input layer, component layer, rule layer and output layer. They perform assigning, fuzzification, blurred fuzzy calculation and the calculation of the defuzzification. The controller network parameters of the model of are the component value ‘m’ of each neurons in the component layer, the width δ and the weight W between rule layer and output layer. Other connection weights of each part are l. In this paper ***i*** is defined as the input of the neurons, y is the output of the neuron, The top right corner mark said the layer of the neurons in, The lower right corner mark said the layer order number of the neurons in. The first layer is input layer. In this layer the

external input of neurons is passed to the next layer directly. The first layer has the effect of transition and allocation in signal transmission, namely

$$\mathbf{Z_m^{(1)} = x_m} \tag{1}$$

In the formula, xm is the mth component of the external input, in this paper, xm is the mth input variable of the controller.

The second layer is component layer. Through the component function the neuron blurs the input data, namely

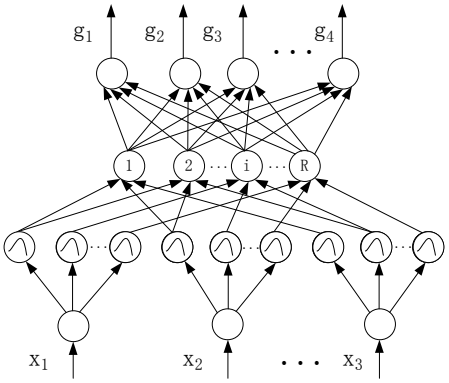

Figure 2 : The structure of the fuzzy neural network controller

$$Z_{mi}^{(2)} = \exp(-\frac{(u_{mi}^{(2)} - m_{mi}^{(2)})^2}{2(\delta_{mi}^2)^2}) = \exp(-\frac{(x_m - m_{mi}^{(2)})^2}{2(\delta_{mi}^2)^2}) \tag{2}$$

In the formula, $u_{mi}^{(2)}$、$Z_{mi}^{(2)}$ are the ith neuron's input and output when the mth input is blured; $m_{mi}^{(2)}$, $\delta_{mi}^{(2)}$ are the component value and the width. The network of this paper divides each network input into five, they are negative big, negative, zero, small and the board. Therefore, using five Gaussian function respectively, namely

$$f(x) = \exp(-\frac{(x_m - m)^2}{2\delta^2}) \tag{3}$$

The third layer is the rule layer."And"the blurred result of the second layer, the fuzzy rules is: set x is a M dimensional vector, component language number value on the universe of discourse of each component are I_1, I_2, ..., $I_{M;}$set Z is a N dimensional vector, component language number value on the universe of discourse of each component are J_1, J_2, ..., $J_{N.}$

Using the network operation realize the inference model, in the form of the if if-then fuzzy rules. In the first layer using m input neuron respectively corresponding to the each component of x variables in the fuzzy rules. On the second layer, respectively, using I_1, I_2, ..., I_M corresponding to the subentry language values A_{11}, A_{12}, ..., A_{MIM} of the if-then fuzzy rules.

In the third layer using product operation implement of inference rules "and". For its expression is

$$Z_r^{(3)} = \prod_{k=1}^{K_r} u_{r_k}^{(3)} \tag{4}$$

In the formula, Kr is the number of all the input variables of the rth neurons in the third layer

The fourth layer is output layer, use the method of weighted square to defuzzy, namely

$$g_n = Z_n^{(4)} = \frac{\sum_{i=1}^{R} w_n y_i^{(3)}}{\sum_{i=1}^{R} y_i^{(3)}} \quad \textbf{(5)}$$

In the formula, W_n is the weights of output layer ; Yi is the output of the sub-network of the ith component fuzzy neural network.[10-14]

The Design of The Predictor

Predictor in this paper is recursive wavelet neural network, including the input layer, hidden layer, structure layer and output layer, the input of the neuron is the output of the neuron in hidden layer, output of structure layer and input layer are the input of the hidden layer. The structure layer neurons is also a kind of memory units, the storage of the hidden layer neurons on the output of the step, the memory let that network has good dynamic performance.

There are three vectors in input layer of the network, they are the error e3 of control object actual output and the output of prediction, the actual output value of y the moment before, output value of the fuzzy neural network controller u (u is u1 or u2, when fuzzy neural network 1 is opened u is u1, u1 is a two-dimensional variables, when fuzzy neural network 2 is opened u is u2, u2 is one-dimensional variable , one output layer nodes and no matter choose which kinds of control mode hidden layer and the structural unit has five nodes.

Network output t_o for the room temperature forecasts the output value of the next moment, the network input o (k) is a 3 dimensional vector, output x (k) and hidden layer structure unit output xc (k) of 5 dimensional vector, network output t_o(k) as 1 dimensional vector, connection weight W1 is 5 x 5 dimensional matrix, W2 is 5 x 3 dimensional matrix, W3 matrix is 1 x 5 dimensional. Because the wavelet neural network is introduced into the scale factor and shift factor, so to increase the flexibility of the network, can be more effectively and make the training process approximation accuracy of target value, training effect is more ideal.

The mathematical model of wavelet Elman neural network as follows:

$$x_c(\mathrm{k}) = \alpha\, \mathrm{x}_c(\mathrm{k}-1) + \mathrm{x}(\mathrm{k}-1) \quad \textbf{(6)}$$

$$x(\mathrm{k}) = \psi\left(\frac{h(\mathrm{k}) - \mathrm{b}_i(\mathrm{k})}{a_i(\mathrm{k})}\right) \quad \textbf{(7)}$$

$$y(\mathrm{k}) = \mathrm{g}(\mathrm{W}^3(\mathrm{k})\,\mathrm{x}(\mathrm{k})) \quad \textbf{(8)}$$

In the formula : $h(\mathrm{k}) = \mathrm{W}^1(\mathrm{k})\,\mathrm{x}_c(\mathrm{k}) + \mathrm{W}^2(\mathrm{k})\,\mathrm{u}(\mathrm{k})$ (9) $\psi(.)$ is the wavelet function. This article takes the Morlet wavelet, set a_i is the wavelet scale coefficient matrix, b_i is the wavelet translation matrix.

set $X = \frac{h(\mathrm{k}) - \mathrm{b}_i(\mathrm{k})}{a_i(\mathrm{k})}$ (10). For the wavelet translation matrix is $\psi(\mathrm{X}) = \cos(1.75\,\mathrm{X})\,\mathrm{e}^{-\frac{X^2}{2}}$ (11), g(·) is the transfer function for the output layer.

THE SIMULATION

Since each parameter of air conditioning room all influenced of such factors as outdoor temperature, indoor equipment, lighting and heat flow, the air conditioning room is a complex thermal system. Therefore, it is difficult to use a precise mathematical model to describe. See the whole air conditioning room as a single object, ignore other objects' accumulation and air flow, see the

temperature in the room is uniform distribution. Assuming that the transfer function of the air conditioning room is: $G(s) = \frac{18}{60s^2 + 17s + 1} e^{-12s}$.

Because as the error value E between the room temperature set point and the actual temperature changes, room control system will choose a different pattern implementation room temperature control, but achieve the critical value Ek needs experiment many times, therefore, this paper only select a smaller temperature difference value and a larger temperature difference value as representatives of the two control methods to compare in the matlab simulation software.

Control mode 1: The control system select control mode 1 when the interference of the room is small. At this time, control object is the air valve and heater motor. Now assume that the current temperature of room is 18°C, air conditioning room setting temperature value is 25°C. Respectively, in the Matlab simulation software using multivariate air conditioning control method and the traditional parallel neural network predictive control method for simulation analysis, the control effect contrast diagram as shown in Figure 3.

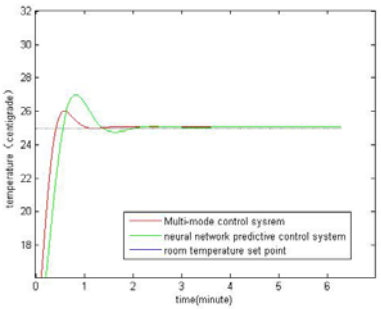

Figure 3 : Simulation diagram 1

It can be seen from the above, when parallel multivariable air conditioning control system is choosed, response time is short, overshoot volume is about 4%, settlement time is about 200s, the steady state error is 0.204%, the traditional neural network predictive control system response time is a bit long, overshoot volume is about 6%, settlement time is about 280s, the steady state error of 0.24%, so when the room interference amount is larger, or it has a larger error between the actual temperature and the temperature set point, control effect of multiple mode control is better than the traditional neural network predictive control system. Compared with traditional VAV control system, parallel multivariate air conditioning control system has the characteristics of higher power, small amount of overshoot, small steady-state error, not only save energy and improve the indoor environment of comfort.

Control mode 2:The control system select control mode 2 when the interference of the room is big, at this time, control object is air valve. Now assume a current temperature of room is 21°C, air conditioning room setting temperature value is 25°C. In the Matlab simulation software using multivariate air conditioning control method and the traditional parallel neural network predictive control method for simulation analysis, the control effect contrast diagram as shown in Figure 4.

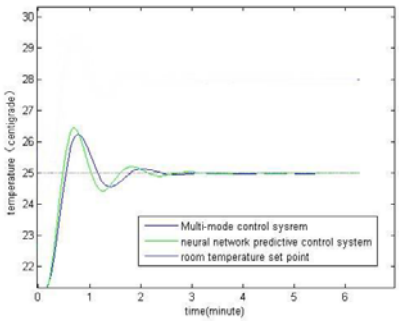

Figure 4 : Simulation diagram 2

It can be seen from the diagram above, this time the parallel variable air conditioning control system and the traditional neural network predictive control system's response time, mediation, the steady-state error is basically the same, parallel multivariate air conditioning control system overshoot volume is about 4%, the traditional neural network predictive control system overshoot volume is about 5.6%, the difference is not big. So when the error between the actual temperature and the temperature set point is small, select parallel multivariate air conditioning control system and traditional variable air volume air conditioning control system the distinction is not very clear, all of them can achieve the result of energy saving.

CONCLUSION

In this paper, the multiple mode control method is introduced to the vav control system, the method sets up two kinds of control mode, choose different control objects under different disturbance in order to achieve rapid adjustment and the characteristics of energy saving, Controller using fuzzy neural network, the predictor using wavelet neural network, combine them, online to establish a neural network prediction model of the object, and use the model output and the actual output of the difference online predictor parameters adjustment. The results show that, the control effect by choosing multi-mode air conditioning control system is much better than the traditional neural network predictive control system. Multiple mode control method has the characteristics of strong robustness, high control precision, the adaptive ability is strong, safe and reliable, energy saving, it has wide application prospect.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under Grant No. 60874103.

REFERENCES

[1] J.C.Dong; Industrial Instrumentation & Automation, **1**, 19-22 **(2001)**.
[2] D.B.Zhang, K.X.Huang; Information and Control, **42(5)**, 583-588 **(2013)**.
[3] X.Q.Jin, X.X.Zhou, C.W.Wang; Journal of Shanghai Jiaotong University, **34(4)**, 507-523 **(2000)**.
[4] Fan.D.X, Variable air volume (VAV) air conditioning system of Simulink modeling and simulation. Harbin Industrial University, **(2007)**.
[5] Guo.X.Y, Journal of shenyang university of technology, **35(1)**, 99-103 **(2013)**.
[6] Z.S.Wu; VAV BOX control algorithm and simulation. South China University of Technology, **(2012)**.
[7] X.Y.Song, H.F.Xu, H.L.Sun; Chinese Journal of Computers, **36(8)**, 1693-1703 **(2013)**.
[8] H.S.Xu, X.L.Hou; Journal of Shenyang Jianzhu University (Natural Science), **27(3)**, 587-591, **(2011)**.
[9] J.T.Choi, Y.H.Choi; Fuzzy neural network based predictive control of chaotic nonlinear systems. IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences, **87**, 1270-1279, **(2004)**.
[10] R.J.Wai, J.D.Lee; Adaptive fuzzy-neural-network control for maglev transportation system. Neural Networks, IEEE Transactions on, **19**, 54-70, **(2008)**.
[11] F.J.Lin, P.H.Shen; Adaptive fuzzy-neural-network control for a DSP-based permanent magnet linear synchronous motor servo drive. Fuzzy Systems, IEEE Transactions on, **14**, 481-495, **(2006)**.
[12] R.J.Wai, C.C.Chu; Robust petri fuzzy-neural-network control for linear induction motor drive. Industrial Electronics, IEEE Transactions on 2007, **54**, 177-189, **(2007)**.
[13] A.Aoyama, F.J.Doyle III, V.Venkatasubramanian; Control-affine fuzzy neural network approach for nonlinear process control. Journal of process control, **5**, 375-386, **(1995)**.
[14] C.D.Li, J.Q.Yi, Y.Yu, D.B.Zhao; Inverse control of cable-driven parallel mechanism using type-2 fuzzy neural network. Acta Automatica Sinica, **36**, 459-464, **(2010)**.