Journal of Southeast University (English Edition) Vol. 26, No. 2, pp. 355 - 358 June 2010 ISSN 1003—7985

Fault isolation of air handling unit based on neural network

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Abstract: Aiming at various faults in an air conditioning system, the fault characteristics are analyzed. The influence of the faults on the energy consumption and thermal comfort of the system are also discussed. The simulation results show that the measurement faults of the supply air temperature can lead to the increase in energy consumption. According to the fault characteristics, a data-driven method based on a neural network is presented to detect and diagnose the faults of air handling units. First, the historical data are selected to train the neural network so that it can recognize and predict the operation of the system. Then, the faults can be diagnosed by calculating the relative errors denoting the difference between the measuring values and the prediction outputs. Finally, the fault diagnosis strategy using the neural network is validated by using a simulator based on the TRNSYS platform. The results show that the neural network can diagnose different faults of the temperature, the flow rate and the pressure sensors in the air conditioning system.

Key words: air handling unit; fault characteristics; fault isolation; neural network

Controllers play essential roles in the heating, ventilation and air conditioning (HVAC) systems. The better optimal control strategy a system has, the more energy saving it can realize. Besides reasonable and optimal control strategies, healthy operation including healthy measuring, controlling and executing components should also be ensured. Without healthy measurement and control, the operation of a HVAC system can never be optimal or reasonable. If there are some faults in the system, for example, the operation conditions may deviate from the optimal operation condition point. As a result, much energy consumption or poor indoor air quality may occur. Moreover, the faults may lead to a decrease in the facilities' lives or even some safety accidents. Consequently, it is essential to develop suitable fault detection and diagnosis (FDD) tools.

The development of FDD in the HVAC field is later than that in spaceflight, nuclear science and automation. Usoro et al. [1] started the fault diagnosis research in the 1980s. As the fault diagnosis tools gradually showed positive effects, more and more scholars began to pay attention to them. The International Energy Agency (IEA) organized many scholars from different countries to develop possible and suitable fault diagnosis tools. Some typical achievements included Annex25[2] and Annex34[3]. After that, the Department of Energy (DOE) in America[4-6] and the ASHRAE Technical Committee[7-9] also organized and sponsored related researches on fault detection and diagnosis in the HVAC field. Recently, it has become more active in western countries.

In China, the application of fault detection and diagnosis in the HVAC field is later than that in western countries. Jiang et al. [10-14] developed related fault diagnosis tools in the HVAC systems.

Two main methods of fault detection and diagnosis have been developed in the HVAC field. One is the model-based method, and the other is the data-driven method. The model-based method has been widely developed. Through comparing the differences between the outputs of the mathematical models and the measured values, which are called residues, the faults can be diagnosed. Obviously, whether accurate mathematical models can be built is a key-point for the application of the model-based method. The data-driven method has been developed recently. The mathematical methods, such as the statistical method, the neural network, the wavelet analysis, etc., are always used to process and analyze the operation data. Through analyzing and comparing the data to be determined with the known ones, the fault diagnosis can be made. The data-driven method does not need to construct mathematical models for the HVAC systems, but many operation data are needed. And the diagnosis efficiency highly relies on the quality and quantity of the data. Fortunately, with the development and application of building automation, the operation data can be easily obtained.

In this paper, fault characteristics in the air handling units are first discussed. Then, a neural network is presented to diagnose faults in the air handling unit. Through training the operation conditions, the constructed network can well recognize the system. When faults occur, the neural network can be used to diagnose them.

1 Fault Characteristics

1.1 Air handling unit

The scheme of an air handling unit is shown in Fig. 1. It includes three control loops: the supply air temperature controller, the outdoor air flow rate controller and the supply air static pressure controller. Here, we focus on the supply air temperature control loop. Through comparing the measurement results of the supply air temperature with the optimal setpoints, the chilled water valve can be adjusted.

1.2 Fault characteristic analysis

In the supply air temperature control loop, the following variables are concerned: the supply air temperature T_{sup} and its setpoint $T_{sup,set}$, the control commands for the water valve C_w, the chilled water flow rate M_w, the supply chilled water temperature T_{ws} and the return chilled water temperature T_{wr}. The common faults include the errors of setpoints, the measuring biases of the supply air temperature, the measuring biases of M_w, T_{ws} and T_{wr}. In addition, the faults of C_w and the

Received 2009-11-15.

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Citation: Du Zhimin, Jin Xinqiao, Yang Xuebin, et al. Fault isolation of air handling unit based on neural network[J]. Journal of Southeast University (English Edition), 2010, 26(2): 355 - 358.

valve usually occur in real systems.

Under summer and winter conditions, these above-mentioned faults always result in different effects. The analyses of these fault characteristics are shown in Tab. 1.

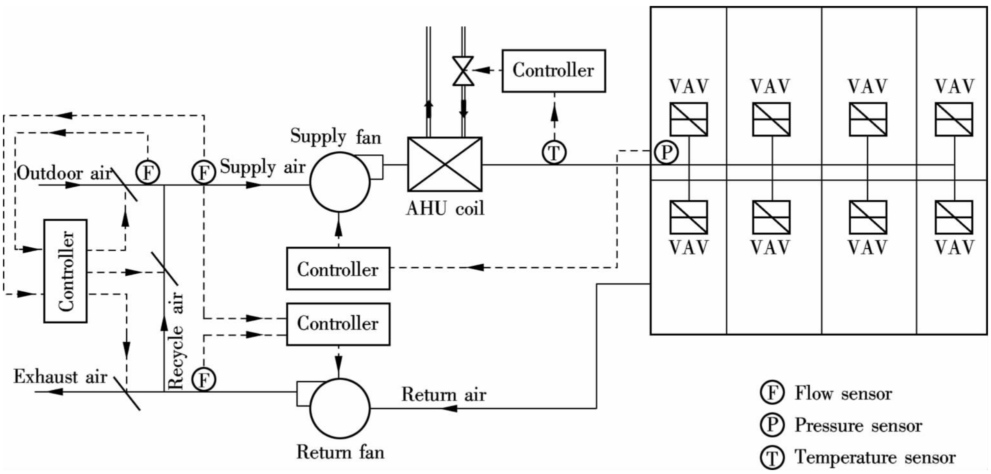

Fig. 1 Scheme of air handling unit

Tab. 1 Influence of faults

Fault	Under summer condition					Under winter condition				
	T_{sup}	T_{ws}	T_{wr}	M_w	C_w	T_{sup}	T_{ws}	T_{wr}	M_w	C_w
Increase in $T_{sup, set}$	+	x	+	−	−	+	x	+	+	+
Decrease in $T_{sup, set}$	−	x	−	+	+	−	x	−	−	−
Positive bias in T_{sup} sensor	+	x	−	+	+	+	x	−	−	−
Negative bias in T_{sup} sensor	−	x	+	−	−	−	x	+	+	+
Positive/negative bias in T_{ws} sensor	x	+/−	x	x	x	x	+/−	x	x	x
Positive/negative bias in T_{wr} sensor	x	x	+/−	x	x	x	x	+/−	x	x
Positive/negative bias in M_w sensor	x	x	x	+/−	x	x	x	x	+/−	x
Increase in C_w	−	x	−	+	+	+	x	+	+	+
Decrease in C_w	+	x	+	−	−	−	x	−	−	

Note: "+" and "−" mean that when faults occur, the related variables increase and decrease, respectively; "x" means that when faults occur, uncertain effect happens.

1.3 Influence of energy consumption

When the measurement results of the supply air temperature are biased, controllers may be misled and mistaken or unsuitable control commands may be taken to adjust the chilled water valve. The comparison of the energy consumption between normal conditions and faulty conditions is shown in Fig. 2. Because the supply air temperature sensor is biased with −2 ℃, the energy consumption is increased by 2%.

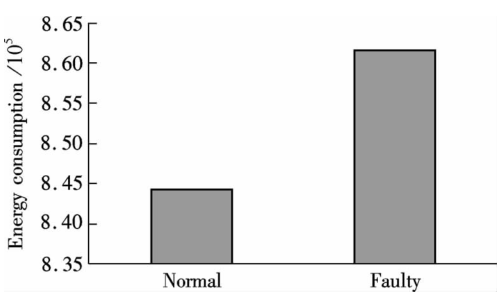

Fig. 2 Comparison of energy consumption

2 Fault Diagnosis

2.1 Neural network

The neural network technique is a valuable pattern recognition method in theory and application. It is widely used in engineering applications, especially in non-linear or complicated systems. It is efficient to learn certain statuses or operation conditions of objective systems. A well-trained network can recognize or distinguish various conditions. Actually, the process of fault diagnosis is essentially a kind of recognition classification or recognition. Therefore, the neural network technique can be used as a diagnosis method.

In general, a neural network is composed of three layers: an input layer, an output layer and one (several) hidden layer(s). There are two main steps to apply a neural network in the diagnosis process. First, the constructed neural network is trained using much characteristic information decomposed from the history data of building automation systems. The training data include normal operation conditions and faulty ones. Secondly, with a well-trained neural network, the condition identification or the fault diagnosis is carried out through comparing the outputs of the condition to be determined with the known ones.

2.2 Diagnosis process

The diagnosis process using a neural network is as follows.

1) The typical training data should be selected as

$$\begin{bmatrix} x_1^1 & x_2^1 & \dots & x_n^1 \\ x_1^2 & x_2^2 & \dots & x_n^2 \\ \vdots & \vdots & & \vdots \\ x_1^m & x_2^m & \dots & x_n^m \end{bmatrix}_{m \times n} \tag{1}$$

2) The neural network is trained by using the historical data. The training process is not stopped until it meets the convergent demand. And the well trained network can recognize the operation of the system.

$$x_i = f_{\text{train}}(x_1, x_2, \dots, x_j, \dots, x_n) \qquad j = 1, 2, \dots, n; j \neq i \tag{2}$$

3) The operation status of the system is predicted.

$$(x_1, x_2, \dots, x_j, \dots, x_n) \xrightarrow{\text{predict}} x_i \quad j = 1, 2, \dots, n; j \neq i \tag{3}$$

4) The fault diagnosis can be made through calculating the relative error ϕ. The relative error denotes the difference between the measurement results and the prediction outputs; that is,

$$\phi = \left| \frac{x_{i,p} - x_{i,m}}{x_{i,m}} \times 100\% \right| \tag{4}$$

2.3 Simulation tests

The simulation tests are made using an HVAC simulator based on the TRNSYS platform. Two fault cases are tested. One fault is the return chilled water temperature sensor biased with 1 ℃. The other is the supply air temperature sensor biased with 1.5 ℃. The prediction results of the well-trained neural network are shown in Fig. 3. And the diagnosis results regarding the relative errors are illustrated in Fig. 4.

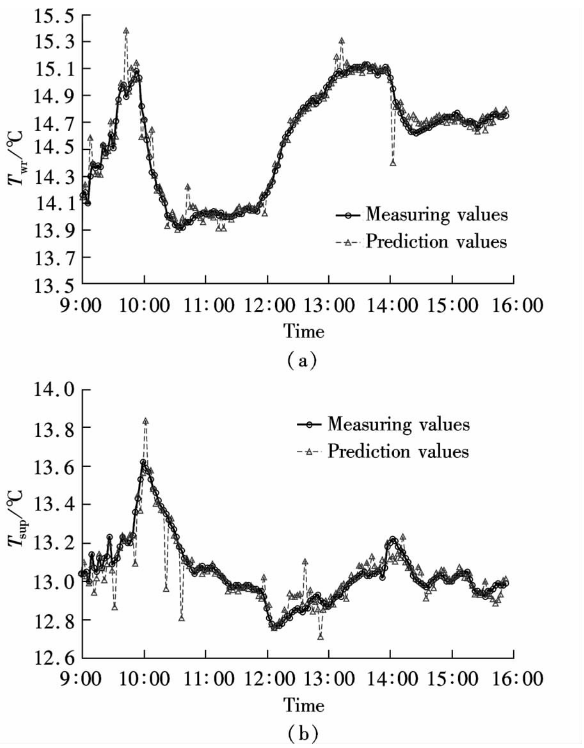

Fig. 3 Prediction of T_{wr} and T_{sup} using neural network. (a) T_{wr}; (b) T_{sup}

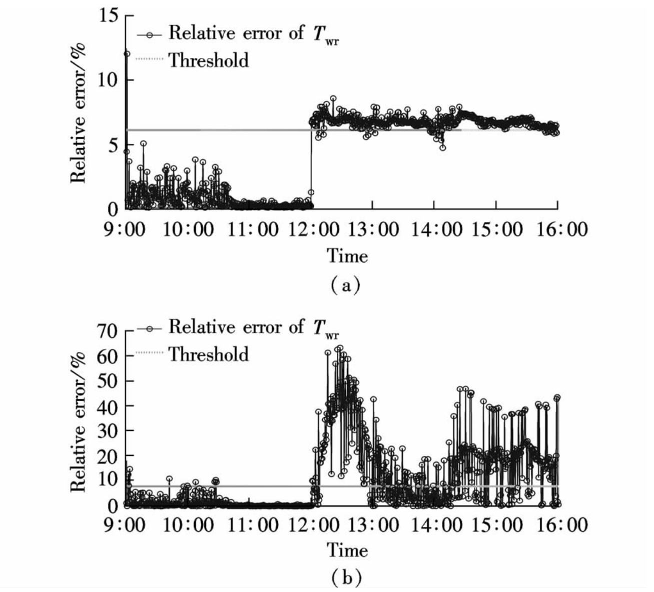

Fig. 4 Diagnosis for faults. (a) Return chilled water temperature sensor; (b) Supply air temperature sensor

3 Conclusion

The characteristics and influences of some faults in an air handling unit are analyzed in this paper. Then, a neural network is presented to diagnose these faults. The neural-network-based method is a data-driven diagnosis method. The diagnosis efficiency of the neural network highly depends on the quantity and quality of the selected training data. The better the training data and the training process are, the higher the diagnosis efficiency is.

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基于神经网络的空调箱故障诊断

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摘要：针对空调系统中的不同故障，分析了空调箱的故障特性，并讨论了不同故障对空调系统能耗及热舒适性的影响. 仿真试验结果表明，送风温度的测量故障会导致系统能耗的增加. 根据故障特性，提出了一种基于神经网络的数据处理方法，用以检测和诊断空调箱中的传感器故障. 该方法首先选取历史数据对神经网络进行训练，实现对系统运行状态的识别和预测. 然后，通过比较测量值与预测值，计算出相对误差，实现对故障的诊断. 最后，利用基于 TRNSYS 的仿真器，对神经网络的故障诊断策略进行了验证. 结果表明，神经网络可以有效诊断空调系统中的温度、流量和压力传感器故障.

关键词：空调箱；故障特性；故障诊断；神经网络
中图分类号：TU83