Research on Multivariable Adaptive Control of HVAC System

Jie YU\textsuperscript{1,*}, Jerry JIN\textsuperscript{2} and Bo HU\textsuperscript{1}

\textsuperscript{1}Institute of Information Science and Technology, Fudan University, Shanghai, China
\textsuperscript{2}Honeywell Integrated Technology (China) Co., Ltds

*Corresponding author

Abstract. HVAC system need be quickly diagnosed the location and location of the fault and find the cause of the failure, and reduce the failure to improve the comfort of users, improve the energy efficiency of buildings. Firstly, features of HVAC system failures were introduced in this paper. Failure correlation and transitivity and hierarchy of faults and parameter alignment were analyzed. On this basis, step size selection of depth neural network model was constructed by statistical-based machine learning. Adaptive depth neural network algorithm was built by weight updating formula. Finally, by an application case, multivariable adaptive control of HVAC System can strengthen the fault prediction and monitoring, can reduce the occurrence of fault, and prolong the life of equipment.

Keywords: HVAC system neural network model, Depth learning.

Introduction

HVAC equipment should have high performance coefficient. Besides strengthening technical research in the stage of design and manufacturing, it is necessary to keep in normal state and achieve optimal operation in the course of operation. It is shown that the energy efficiency of heat pump operation is about 10% lower than that under the standard experimental condition, some installation is not compatible. The energy efficiency of a suitable heat pump can be reduced by 30%. Recently, a study shows that the HVAC system in a commercial building can achieve a 20 to 30% energy saving effect after fault detection and diagnosis and debugging. Therefore, it is possible to strengthen the fault prediction of the HVAC system, quickly diagnose the location and location of the fault and find the cause of the failure, and reduce the failure. Once the fault diagnosis system can automatically identify the fault of the HVAC device and its system, and notify the operator in time, the system can get immediate repair, can reduce the time of the operation of the equipment, and can also reduce the maintenance cost and unpredictable equipment shutdown time..

In recent years, people have done some significant work on HVAC adaptive control, but it is mainly limited to single input/single output system. On the basis of thermodynamic analysis, this paper designs a multi-input/output system based on linear system and adaptive control theory. The method studied in this paper can detect the change of load in advance. Furthermore, the minimum risk decision-making algorithm is used to make the decision, which improves the response rate, human comfort and energy saving. In this paper, features of HVAC system failures were introduced in this paper. Failure correlation and transitivity and hierarchy of faults and parameter alignment were analyzed. On this basis, step size selection of depth neural network model was constructed by statistical-based machine learning. Adaptive depth neural network algorithm was built by weight updating formula. Finally, by an application case, multivariable adaptive control of HVAC System can strengthen the fault prediction and monitoring, can reduce the occurrence of fault, and prolong the life of equipment.
Features of HVAC System Failures

Failure Correlation and Transitivity
A HVAC system is an interconnected system consisting of pipes connected to various air. If one component of the system fails, it will affect the operation of the other components. For example, in a steam compression refrigeration cycle, if the cold water pump fails, the amount of water passing through the evaporator per unit time decreases, the evaporation temperature and the evaporation pressure decrease. Compression ratio of the compressor increases, the power consumption increases, the COP of the system decreases, and the compressor will be damaged seriously. Hence, faults have significant correlation and transfer characteristics. Due to HVAC, the fault of the system, the fault of one component will affect the normal operation of other components and cause the change of several parameters, so it is sometimes difficult to judge the location of the fault. It is also difficult to find out data and which are the result data, which makes the fault diagnosis complicated.

Hierarchy of Faults and Parameter Alignment
Although HVAC systems are very complex, they are also composed of subsystems at different levels. For example: Cooling water system, chilled water system, refrigerant system, automatic control system, etc. The faults that occur always belong to a level in which there is always a change in one or several characteristic parameters. If the fan in the condenser fails, it is part of the condensing system, which will cause changes in the volume of air passing through the condenser coil and in the outlet temperature of the condenser. The air volume and the air outlet temperature are the characteristic parameters (also called cause parameters) of the fault, so the fault has the characteristics of hierarchy and parameter correspondence. Using this characteristic of the fault, we can propose a diagnostic mode. In addition, that cause parameter and the result parameters are classify so as to realize correct fault diagnosis.

HVAC System Fault Analysis Based on Depth Learning

Step Size Selection of Depth Neural Network Model
In that phase of train the depth learning model, the result gradient needs to be multiplied by the step size each time the parameters are update. The R is the learning rate. It is also called the training step. The improper selection of learning rate will lead to the slow optimization process of depth learning gradient method. In the conventional method, the learning rate is a global constant. That is, the step size of iteration is fixed value, and it is necessary to select the appropriate step size according to experience and constant attempts to achieve global optimization. However, when the step size is too large, it will cause convergence oscillation and the global optimization cannot be achieved. When the step size is too small, the training process will slow down and may fall into local optimization. Therefore, an appropriate learning step size is selected.

The influence on the results of the deep neural network is very great. In statistical-based machine learning, a simple probability distribution model, such as a Gaussian distribution or a data distribution, is usually preset for model parameters such as steps, distribution and so on. However, in the deep neural network of graph structure, the selection of learning step size is usually tried according to the experience or preliminary analysis of the researchers. This method can lead to a time-consuming and effort-consuming process of building models, and often unable to find appropriate learning steps.

Adaptive Depth Neural Network Algorithm
By introducing the idea of an adaptive learning rate, the learning rate (i.e., learning step size) is not a constant value after the initial selection. The corresponding adjustments are made by iteration, and this adjustment does not require human control. Comparing the gradient direction of the weight
according to the objective function obtained after the current iteration with the gradient direction obtained after the previous iteration, if the two gradient directions are the same. Then the size of the learning rate is increased, if the two steps are opposite, that is, the learning rate is decreased. According to the weight updating formula described above, after introducing the adaptive learning rate, the new weight updating formula is as follows:

\[
W_{ij}^k = W_{ij}^{k-1} - \frac{\partial E}{\partial W_{ij}} r(k) r(k) = \alpha^k r(k-1)
\]  

(1)

For each update, we have a parameter \( \lambda \) to adjust the learning rate as follows:

\[
\lambda = \begin{cases} 
1 & \text{if } \text{sgn}(W_{ij}^k W_{ij}^{k-1}) = 1 \\
-1 & \text{if } \text{sgn}(W_{ij}^k W_{ij}^{k-1}) = -1 
\end{cases}
\]

(2)

Since the value is 1 or -1, in order to ensure that the range of 0-1 and 1-changes. If take 1 here, the rate is increased, thereby accelerating convergence. If the objective function changes too much and the convergence is missed, the learning rate is decreased. The newly improved network avoids the problem of gradient disappearance or expansion. Therefore, it solves the difficulties of many successful depth learning models in back propagation training. In the classical gradient descent optimization algorithm, when the weight \( w \) is corrected after each iteration.

Only the parameters are corrected according to the negative gradient direction at that time. The accumulated experience in the past can correct the error of this gradient to prevent excessive dependence on the current gradient. Therefore, it often oscillates the learning process and converges slowly. Here, on the basis of the proposed adaptive learning rate algorithm, a momentum term is added to consider the previous experience. Therefore, the final weight update formula is:

\[
W_{ij}^k = W_{ij}^{k-1} - r(k)[(1 - \beta) \frac{\partial E}{\partial W_{ij}^k} + \beta \frac{\partial E}{\partial W_{ij}^{k-1}}]
\]

(3)

Here, the adaptive rate term is the gradient value after the k-th iteration and the gradient value after the second iteration, because the weight of the influence of this gradient and the previous gradient on the descent optimization is taken into account. The value is between 0-0.5, and the specific value can be adjusted according to the data set itself within the range.

**Application**

Here, the model training process is characterized by the recognition error rate of the model, as shown in the following figure. The decreasing process of the recognition error rate also reflects the convergence process of the objective function, the abscissa represents the sequence number of the training iteration, the training of each model takes a total of 800 iterations. Take the number of main elements as 5, and the SPE monitoring process is as shown in Figure. 1.
In that invention, the measure variables of 8 sensors in the fault monitoring and diagnosis platform of the refrigeration dehumidifier are taken to form a KPCA diagnosis model. These variables are the inlet air temperature, the outlet air temperature, the inlet water temperature, the outlet water temperature, the inlet air relative humidity, the outlet air relative humidity, the outlet air quantity and the outlet water quantity, respectively. For the first sensor-only variable (intake air temperature), the above-mentioned 4 is introduced respectively.

Among them, the first 200 samples are normal conditions, and the last 200 samples are fault conditions. All kinds of faults can be obviously monitored. It can be seen that the contribution percentage of the first variable changes the most (increases the most) after the occurrence of the fault, thus concluding that the fault occurred on the first sensor, which was perfectly consistent with reality. According to the figures, it can be seen that the KPCA can be used to monitor and identify the four common faults of the sensor. It should be pointed out that the linear PCA method is not satisfactory for the fault with reduced accuracy level. It can be seen that the dynamic recursive particle swarm optimization algorithm is used to control the motion of the swing test stand, and its control accuracy is further improved compared with PID control algorithm and dynamic particle swarm optimization algorithm, which improves the stability and accuracy of the electro-hydraulic servo control system and adapts to the dynamic time-varying environment.

Conclusion

In this paper, features of HVAC system failures were introduced in this paper. Failure correlation and transitivity and hierarchy of faults and parameter alignment were analyzed. On this basis, step size selection of depth neural network model was constructed by statistical-based machine learning. Adaptive depth neural network algorithm was built by weight updating formula. Finally, by an application case, multivariable adaptive control of HVAC System can strengthen the fault prediction and monitoring, can reduce the occurrence of fault, and prolong the life of equipment. At the same time, it can also provide the owner with continuous and comfortable indoor environment, which can improve the comfort of users, improve the energy efficiency of buildings, increase the reliability of HVAC system, and reduce the economic loss.

References


