Research on Decoupling Control in Temperature and Humidity Control Systems

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Abstract. Temperature and humidity are two highly coupled variables in a control system, which need to be decoupled for effective control. Moreover, the coupling problem may get more severe and the two control loops may produce a strong interference to each other that can cause system instability when the humidity is measured by dry-and-wet bulb method. In this study, a control method based on fuzzy-neural-network was studied for solving the coupling problem. The shape of membership function can be adjusted in time by using a wavelet basis as the fuzzy membership function. An effective real-time decoupling control system for temperature and humidity could be realized by neural network fuzzy inference. Decoupling control tests were conducted in a control room with 1.6 m × 1.0 m × 4.0 m. The results show that the performance of the control system on dynamic response speed, stability, and anti-jamming have been improved after decoupling.

Keywords: Dry-and-wet Bulb Method; Coupling Problems; Fuzzy Neural Network; Wavelet Basis; Temperature and Humidity.

1 Introduction

Coupling problems widely exist in nonlinear time-varying systems with multiple inputs and outputs. One of the major technical difficulties in designing a measurement and control system is to control the coupling objects effectively [1]. The objects need to be decoupled for effective control. Most of traditional method of decoupling control is built on the basis of a mathematical model, however, it is hard to establish accurate mathematical model for many production process [2]. As a kind of multivariable nonlinear system, control systems of temperature and humidity are widely embedded in many products such as temperature and humidity environmental chambers, drying box of agricultural products, food processing ovens, etc [3-5]. The performance of those products mainly depends on the control veracity of temperature and humidity, however, there is coupling between the two variables, and it is very difficult to improve the accuracy for the needs of high quality products by using traditional control methods [6]. Decoupling Control has been already proved to be a

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key technique for building temperature and humidity control systems for high quality products.

In recent years, fuzzy neural network provides a new way to solve problems that can't be done by traditional methods in the field of control [7]. Fuzzy control does not require precise mathematical description of the control object in achieving good control of the system, however, factors such as nonlinear, time-varying and random interference of the system may result in inappropriate or incomplete fuzzy control rules which will affect control performance [8, 9]. Neural network has good capacities in nonlinear processing, self-learning, self-organizing, and adaptability although it needs long training time and its dynamic characteristics are not ideal [10]. Fuzzy neural network is the combination of fuzzy control and neural network, and it can not only integrate the merits of both fuzzy control and neural network, but also can overcome their shortcomings. Therefore, this new method makes it possible to build higher precision control systems in products with coupling problems.

Nowadays, products with core of temperature and humidity control system such as environmental chambers are widely used in agriculture, aerospace, military, electronics, and other fields. It is the objective of many scientists and engineers to improve the performance of those products and to meet the requirements for higher accuracy in control process. In order to look for a new way in designing high quality temperature and humidity control systems, a novel method was proposed to improve the decoupling effects in a temperature and humidity control system in the paper.

2 Coupling in Temperature and Humidity Control Systems

The temperature and humidity will have effect on each other in an environment; changes from temperature will result in humidity fluctuating, and the temperature will also get a certain influence from humidity variety.

Relative humidity (RH) is usually measured by dry-and-wet bulb method: To detect air temperature by a thermal resistance sensor, namely the dry-bulb temperature; and to detect the temperature of the veil kit soaked in distilled water by a same thermal resistance sensor, namely the wet-bulb temperature. The mathematical formula can be derived through the heat transfer theory and thermodynamic theory as follows:

$$X_h = \frac{E_s - NP(T_g - T_s)}{E_g} \times 100 \tag{1}$$

Where: X_h is the relative humidity %; E_s is the saturated water pressure under wet-bulb temperature; E_g is the saturated vapor pressure under dry bulb temperature; N is a constant related with wind speed; P is atmospheric pressure; T_g is the dry-bulb temperature ; T_s is the wet-bulb temperature.

The control of temperature and humidity is generally based on the principle of balances on temperature and humidity. Customarily, temperature homeostasis is realized through heating by a heater and refrigerating by a cooler or adding cold air; simultaneously, the humidifier (usually produced by heating steam) is work together with a dehumidifier (Generally by cooling and dehumidification condensation through the heat exchanger) for achieving dynamic equilibrium of humidity.

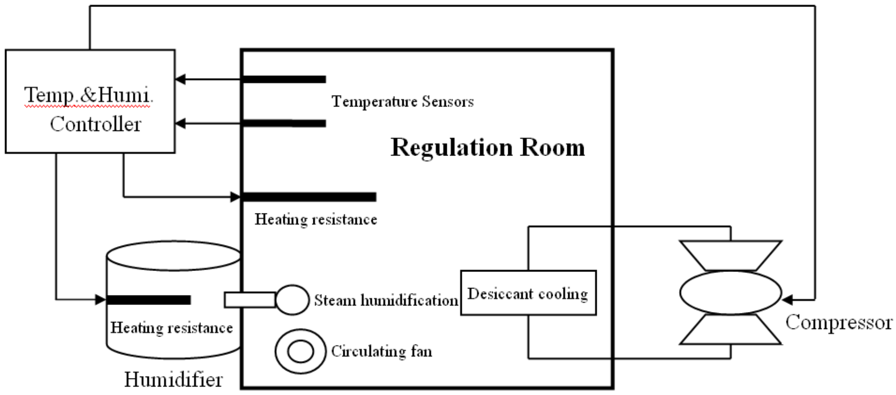


Fig. 1. Schematic diagram of measurement and control for room temperature and humidity

However, this kind of method for temperature and humidity monitoring and control may produce coupling problem. As Fig.1 show, the temperature of dry bulb will decrease quicker than the wet bulb when the temperature in the regulation room drops for some reason; consequently, by formula (1), the measurement value of relative humidity will increase although the actual humidity in the room has not changed. Then, the humidity control loop will start to work for adjusting the humidity falsely. It might be called systematic error which is brought by the measured value of the relative humidity [11], and will exacerbate the coupling effect between the temperature and humidity in the room. Therefore, coupling problems may get more severe and the two control loops may produce a stronger interference to each other that can cause system instability when the humidity variable parameter is measured by dry-and-wet bulb method although it is the most popular way in humidity measurement.

3 Principles and Methods

3.1 Control Systems of Temperature and Humidity

Input and output control systems for temperature and humidity can be described as follows:

$$\begin{bmatrix} Y_t(k) \\ Y_h(k) \end{bmatrix} = P[X_t(k), X_t(k-1), X_h(k), X_h(k-1), Y_t(k-1), Y_h(k-1)\ ] + \begin{bmatrix} T_t(k) \\ T_h(k) \end{bmatrix} \quad (2)$$

Where: Y_t is the output of temperature, Y_h is the output of humidity; X_t is the input of temperature, X_h is the input of humidity; T_t is the system disturbance and measurement noise of temperature, T_h is the system disturbance and measurement noise of humidity.

3.2 The method of Wavelet

A wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components [12]. Usually, one can assign a frequency range to each scale component. Each scale component can then be studied with a resolution that matches its scale. A wavelet transform is the representation of a function by wavelets. The wavelets are scaled and translated copies (known as "daughter wavelets") of a finite-length or fast-decaying oscillating waveform (known as the "mother wavelet"). Wavelet transforms have advantages over traditional Fourier transforms for representing functions that have discontinuities and sharp peaks, and for accurately deconstructing and reconstructing finite, non-periodic or non-stationary signals. Information can be effectively extracted from signals by wavelet transform, which is a good way for local analysis [13]. Continuous wavelet transform is a waveform transform that obtain continuous values through scaling parameter *a* and translating parameter *b*. In practical applications, *a* and *b* will be discretized and all the discrete wavelet form a function group which can be used as a base function.

For the advantages of wavelet described above, Wavelet basis [14, 15] was used as the membership function of fuzzy neural network in our study, and it can be expressed as follows:

$$H_{a,b} = H\left[\frac{(x-a)}{b} \right] \tag{3}$$

Where: *a* is the expansion factor; *b* is the translation factor. The base expression of mother wavelet *H (•)* is as follows:

$$H(x) = e^{\left(-x^2/2\right)} \cdot cos\left(x/2\right) \tag{4}$$

3.3 Decoupling Control Based on Fuzzy Neural Network

The decoupling control structure of temperature and humidity based on fuzzy neural network (shown in Fig. 2) is consists of four layers, which includes an input layer, a fuzzy layer, a fuzzy rules layer and an output layer.

(a) Input layer: Changes of temperature and humidity (X_t, X_h) will be put into the neural network, and the input value of each neuron will be converted to the fuzzy domain [-1, 1].

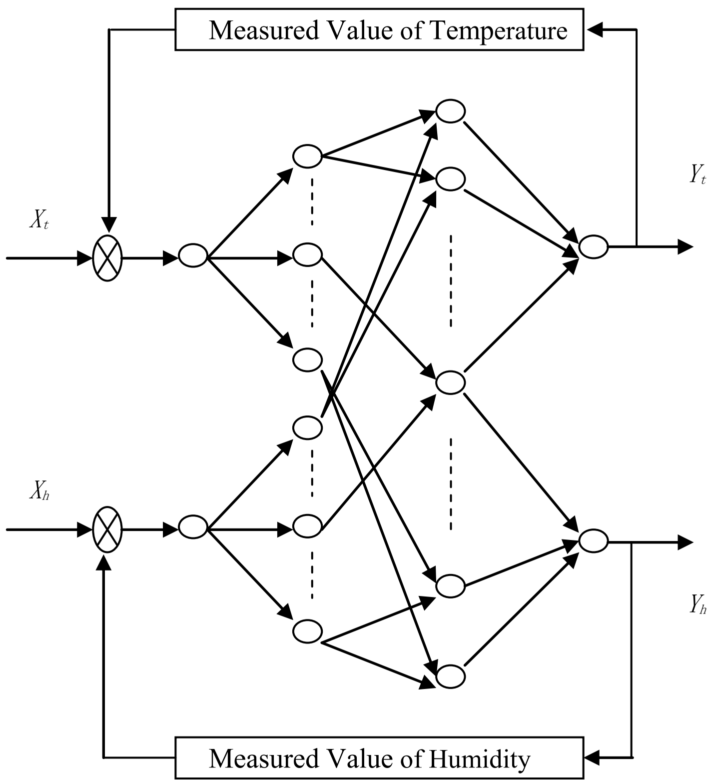


Fig. 2. Control structure of temperature and humidity based on fuzzy neural network

(b) Fuzzy layer: Fuzzy variables will be obtained from the inputs; and wavelets are used as the fuzzy membership function in our study. The affiliation between the inputs and the fuzzy linguistic variables is as follows:

$$H_{ij}(x_i) = e^{\left(-(x_i - b_{ij})^2 / 2a_{ij}^2\right)} \cdot \cos\left[(x_i - b_{ij}) / 2a_{ij}\right] \quad \textbf{(5)}$$

Where: i = 1, 2; j = 1, 2 ... N; a_{ij} , b_{ij} are the corresponding dilation factor and translation factor.

(c) Fuzzy rules layer: each neuron represents a fuzzy rule, which will export the corresponding fitness of rules.

(d) Output layer: Defuzzfication will be achieved, and the output will be normalized in this layer.

4 Results and discussion

In order to see the validity of the control method in our study, test works were done in a control box with the dimensions of 1.6m × 1.0m × 4.0m, and the total power of the control box is about 16.5kw; as shown in Fig.1, the control box is made up of heater, evaporator, compressor, circulating, and Temp.&Humi. Controller.

Fig.3 shows a response curve of temperature and relative humidity before and after decoupling when the set value of temperature is changed from 37 ℃ to 28 ℃ and humidity is changed from 60% to 82% in our test work; Fig.3a and Fig.3b are the response curves before and after decoupling respectively. From Fig.3a, it can be observed the temperature reached the predetermined value (28 ℃) after about 14 minutes but the humidity still not reached a steady state half an hour later, and the overshoot is more than 7%RH; The change of temperature and humidity has brought more serious coupling to the humidity control. From Fig.3b, we can find the temperature and humidity reached the predetermined value after about 11 minutes; the overshoot of humidity is less than 1%, and the overshoot of temperature is less than 1 ℃. This shows that the decoupling control is successful by the way of fuzzy neural network in the changed process. In addition, from Fig.3a and Fig.3b, it can also be found that the time needed for reaching the setting value is 1 minute shorter after decoupling, which suggesting that the changes of humidity can also have effect on temperature control.

Fig.4 shows another response curve of temperature and relative humidity before and after decoupling when the humidity is not changed(60%RH) but the set value of temperature is changed from 50 ℃ to 40 ℃; Fig.4a and Fig.4b are the response curves before and after decoupling respectively. From Fig.4, It can be found that the temperature reached the set value(40℃) after about 6 minutes under decoupling control (see Fig.4b) and the change of humidity caused by temperature also returned to the original(60% RH); However, without decoupling, it took more than 15 minutes for the humidity returning its original value as the measured value of humidity rose because of temperature dropped. This further shows that the system achieved a good control effect by the way of fuzzy neural network and the response speed has also been improved a lot. In addition, from Fig.4a, at about the 6^{th} minute, we can notice that there is a short time interval in which the measured value of humidity is lower than its set value from the; it is because that the control loop of humidity took effect falsely as the drop of temperature resulted in the measured value of humidity increased (detail reason is included in the second part of this paper); however, the coupling problems does not exit any more when decoupling control was used according to Fig.4b.

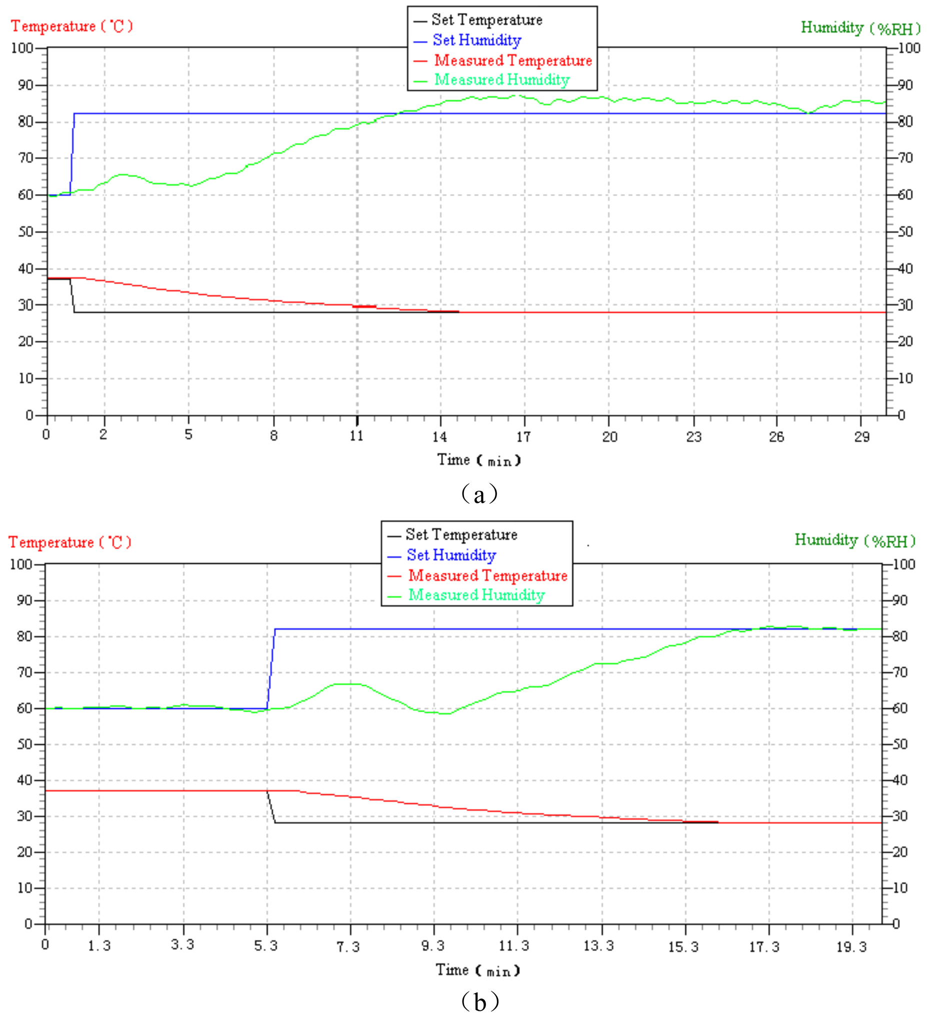
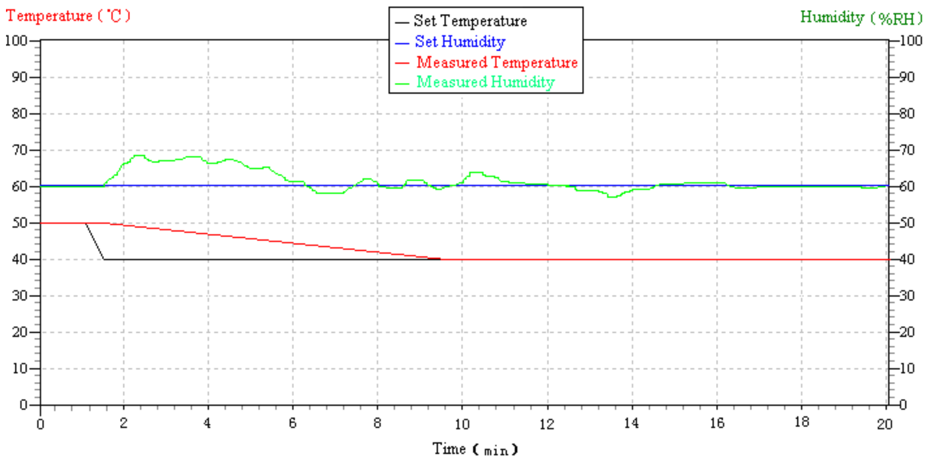
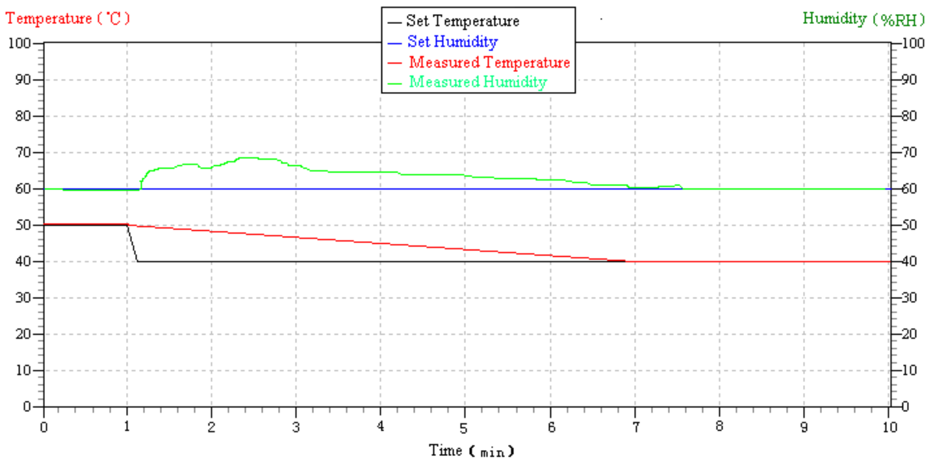


Fig. 3. Response curves of temperature and relative humidity before and after decoupling（1）



(a)

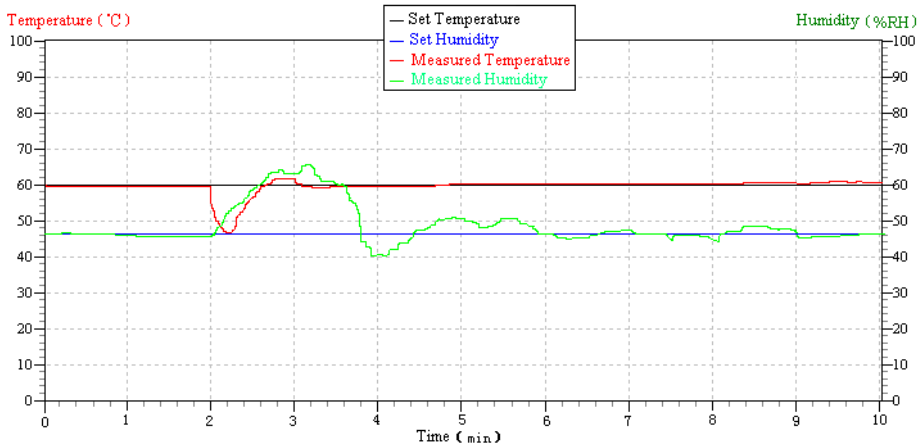


(b)

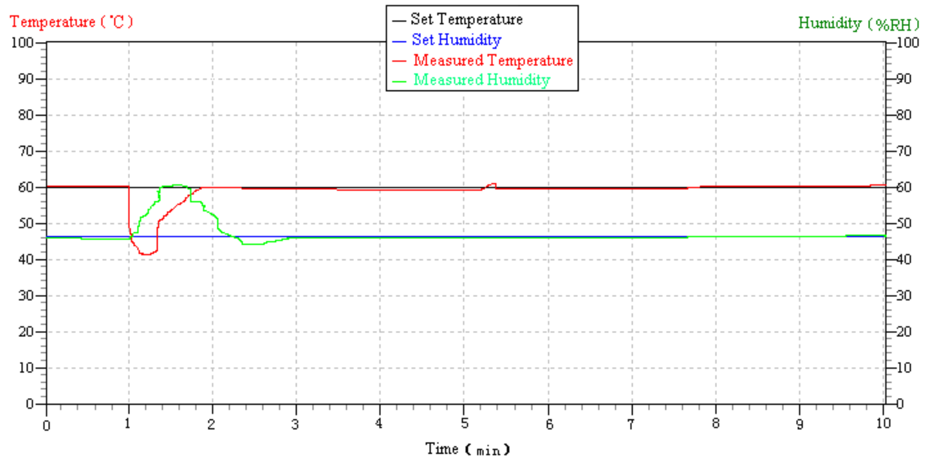
Fig. 4. Response curves of temperature and relative humidity before and after decoupling（2）

Fig.5 shows variations of temperature and relative humidity when the measured temperature value fell because of disturbance from the outside world; Fig.5a and Fig.5b are the variations of temperature and relative humidity before and after decoupling respectively. From Fig.5a, it can be found that the measured value of the temperature was suddenly decreased about 14℃ at the 2nd minute(From 60℃ to 46℃) for outside interference; it took more than 7 minutes for the humidity return to steady state although the temperature recovered to 60 ℃ about 1.5 minutes later as the temperature control loop took effect. From Fig.5b, the measured value of the temperature was suddenly decreased about 18℃ (From 60℃ to 42℃) at the first minute for outside interference; It only spent about 2 minutes for the humidity recover from the interference and recover time of the temperature is less than 1 minute although the interference is more serious compare to Fig.5a. Comparing Fig.5a and

Fig.5b, It can be indicated that changes in temperature had brought a greater impact on humidity control; therefore, for achieving a humidity control loop with high anti-jamming capability, we should find good ways to decrease the coupling effect from temperature changes, which is a most important factor that should be considered in designing control systems of temperature and humidity.



(a)



(b)

Fig. 5. Variations of temperature and relative humidity before and after decoupling when measured values of temperature fall

Usually, there is coupling in measurement and control systems of temperature and humidity; the change of temperature and humidity can take effect on each other's control loop. Systematic error caused by the coupling described in the second part of this paper is one of the main factors in the performance of control systems, which can reduce the anti-interference ability. Therefore, it is very important to find a way to solve the coupling problem. The fuzzy neural network was used for its good performance of local anomaly identification. Fig.3, Fig.4, and Fig.5 show that the method tried in this paper has achieved good decoupling effect; the decoupling control systems has a strong anti-interference ability, fast response, smaller overshoot, and high stability.

5 Conclusions

Systematic error brought by the measured value of relative humidity is unavoidable, which will exacerbate the coupling effect in measurement and control systems for temperature and humidity. Fortunately, there are some decoupling ways to reduce the effect of errors and improve control precise. Most of traditional method of decoupling control is built on the basis of mathematical models; coupling from measured value errors could be reduced by mathematical compensation, however, the humidity and the temperature themselves are a pair of coupled variables, which also need to be decoupled. Moreover, it is hard to establish accurate mathematical model for many production process. Whereas fuzzy neural network can provide new ways in decoupling control, which does not require precise mathematical description of control objects.

The membership function is a generalization of the indicator function in classical sets, which were introduced by Zadeh in the first paper on fuzzy sets (1965). In fuzzy logic, it represents the degree of truth as an extension of valuation. One of the most important factors on the effect of the fuzzy neural network is the membership function we chose. Our primarily study shows that it is a good choice to put wavelet basis as the membership function of fuzzy neural network for decoupling control.

This study provided scientific analysis on coupling problems of measurement and control systems for temperature and humidity, which is important for better understanding coupling problems in control process for this kind of system, and thus improving decoupling ways for control loops. Although more experiments should be done in different type of environment to further confirm our decoupling way, the research offered a novel try in designing high quality temperature and humidity control systems on technical theory and engineering design. Following this work, further verification experiment and scientific evaluation will be done in the future.

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