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Research Article

A Kind of Temperature and Humidity Adaptive Predictive Decoupling Method in Wireless Greenhouse Environmental Test Simulation System

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Abstract: In order to solve the strong coupling characteristic of the temperature and humidity in wireless greenhouse environmental simulation test system which is with nonlinear, big lag, strong coupling, time-varying characteristics and so on, this study proposed an adaptive prediction decoupling method based on dynamic matrix control algorithm. This method can effectively overcome the influence of control accuracy that is caused by serious loss of matching control model. In order to validate the effectiveness of the proposed algorithm and compared with PID control algorithm by simulation experiment. The each mode for heating and humidification was obtained by step response method and on the basis of the model, the PID and forecast decoupling simulation were obtained separately. The Simulation and experimental results show that the adaptive predictive decoupling algorithm can effectively weaken dynamic coupling between temperature and humidity and the control system performance was greatly improved.

Keywords: Adaptive predictive decoupling algorithm, DMC algorithm, PID, wireless sensor networks

INTRODUCTION

Wireless sensor networks has characteristics with the number of nodes, density, low cost etc, so it needn't support with energy and communications facilities and so on and it can self-organized networks at any time and place, the application in greenhouse is more and more extensive (Wu, 2006; He, 2002). Wireless sensor network is composed of sensor nodes, sink nodes, the data collection module and the user receiving terminal and son on and the hardware is mainly composed of single-chip microcomputer and sensors etc. The high temperature and humidity environment in greenhouse can damage components surface and the element insulation is destroyed and resistance is changed and so on (Liu *et al*., 2004). When the temperature and humidity get to a certain critical point especially, the performance of nodes will take place key changes. In order to test which different temperature and humidity have influence on the nodes, it is important practical significance to develop a high control precision temperature and humidity environment simulation system. Temperature and humidity control system is a multivariate nonlinear dynamic system which is with big lag, strong coupling and time-varying characteristics and there are a lot of interferences. It is difficult to realize temperature or humidity independent control at the same time due to coupling. In order to weaken the interaction between temperature and humidity and in the premise of stability, they need to be decoupled.

In engineering practice, many decoupling theory is difficult to get the widely application due to the design method and formula are too complicated. For the traditional decoupling, in order to ensure decoupling performance in steady state and sacrifice dynamic performance, the control accuracy is not high. Adaptive decoupling need online identify the object model, for many interferences complex system and algorithm is more complex, thus the amount of calculation is greatly increased, the adaptation ability in disturbance is poor, the anti-interference ability, namely, system robustness is not strong. Robust decoupling can discuss specific decoupling design method to specific system, in order to reduce the decoupling controller to the sensitivity of the system parameters and can not realize the maximum decoupling at the premise of satisfying the stability and robustness the same time. The decoupling compensator parameters in fuzzy decoupling is offline ensured by experience method of trial and error, once the control rules are determined, its are hard to change, so the adaptability is poor. For neural network decoupling, many decoupling strategy are with compensatory and its can only rely on the simulation to verify. Forecast decoupling don't need accurate mathematical model, it is easy to build model and it easy to implement in

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project, the Dynamic Matrix Control (DMC) in forecast decoupling only need step response model of object, it is not high to model structure demand, so it has been widely applied in complex industrial control. In view of the characteristics such as large lagging, strong coupling and time-varying between temperature and humidity in greenhouse simulation system, a greenhouse WSN node environment test system that has high control accuracy and lower cost was independent designed and an adaptive decoupling method based on dynamic matrix control was proposed, compared with PID, simulation and experimental results shown that the proposed strategy greatly improved the control performance.

SYSTERM STRUCTURE AND WORKING PRINCIPLE

The whole system structure and control principle are shown in Fig. 1 and 2, Industrial control PC machine is taken as the upper machine of system and it is mainly used to do algorithm operation, display system running state and data storage and so on. Control module is mainly composed of temperature and humidity testing device, control module, actuators and controlled object. Controller is composed of heating DMC module and refrigeration DMC module of temperature channel, humidifying DMC module and dehumidification DMC module of humidify channel and adaptive decoupling module between the two channels. In order to eliminate the mutual influence between the temperature and humidity channel, the adaptive DMC decoupling controller decomposed coupling system into two independent SISO system which take use of feed-forward compensation thoughts according to the measured and set value of temperature and humidity, so the corresponding actuator control volume is obtained by the single variable DMC algorithm, the control of temperature and humidity is realized.

- **Heater working principle:** The function relationship between duty ratio of heater control signal and heater power, the power regulation of heating power is realized by adjusting the duty ratio and the precise control of heat intensity is realized.
- **Humidifier working principle:** In this study, the humidifying is realized according to the principle of the ultrasonic, the liquid water is directly converted fine mist whose particles is small by ultrasonic and it is good real-time, high control precision and low energy consumption. According to the measured and set value of the humidity, the output current of MCU I/O port is adjusted by the program and the exchange energy control is realized, so as to achieve efficient control of wet strength.

METHODOLOGY

Dynamic Matrix Control (DMC) is a kind of prediction control algorithm based on the step response, it was put forward by the Culter in 1980 (Qian *et al*., 2007). Model adopts the step response model of the controlled object which is easy obtained in engineering and the algorithm is simple, the amount of calculation is small and has a good robustness. DMC directly detected response (impulse response or step response) from field by process dynamic behavior information

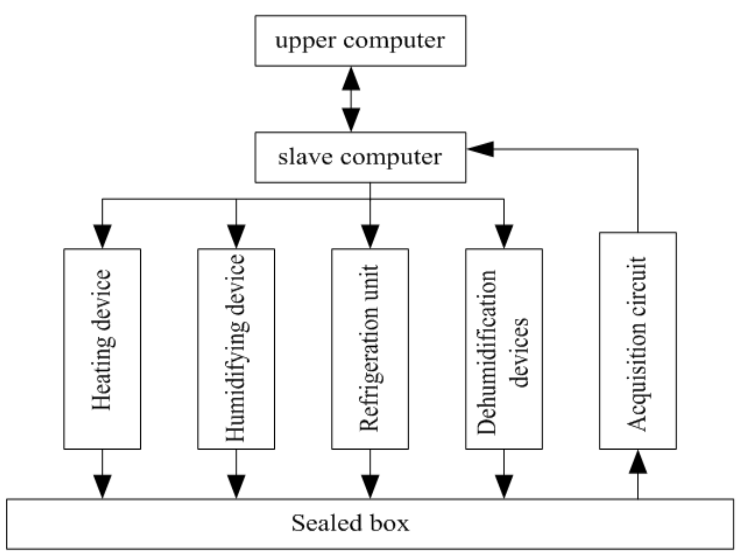

Fig. 1: System structure chart

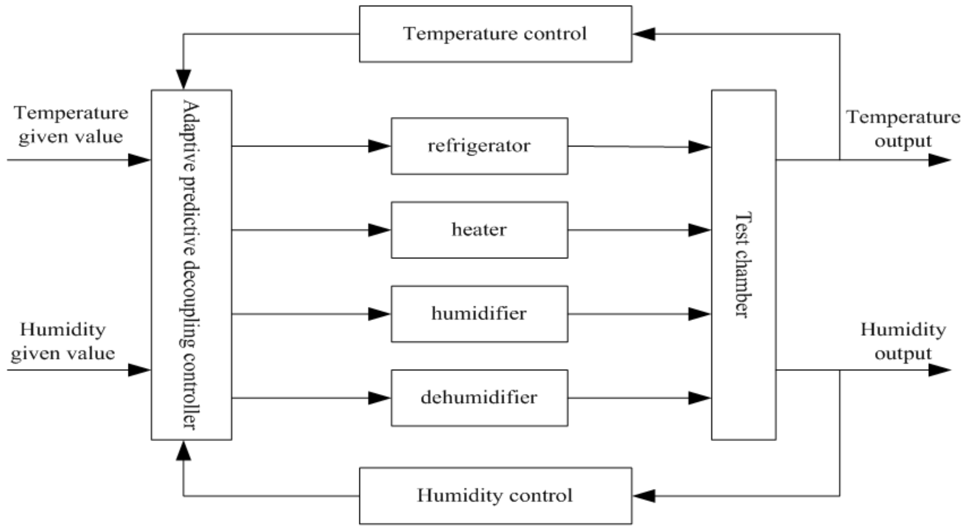

Fig. 2: System control principle diagram

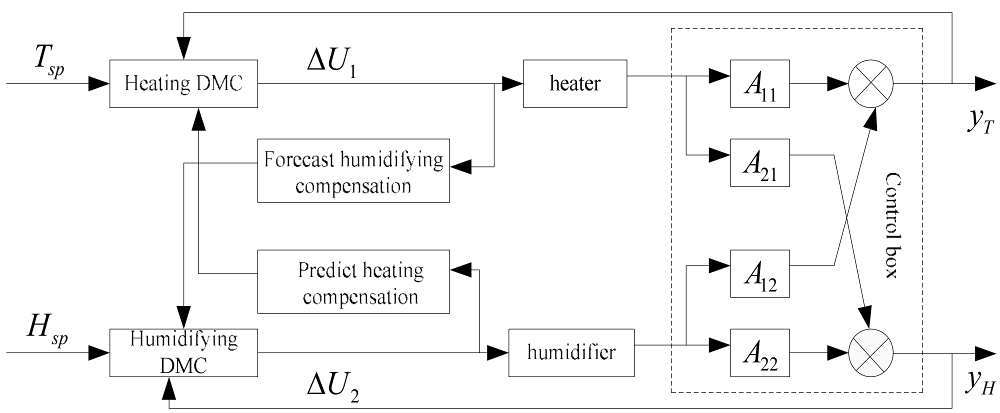

Fig. 3: DMC decoupling algorithm principle diagram

and don't have to know prior knowledge of parameters and structure of the process model and so on, do not need build mathematic model of the system through the complicated system identification, namely, it is used to design the control system according to a optimization index, so as to determine time sequence of a control amount and the error between controlled volume within a period of time and desired trajectory after soft-changed is minimum. Dynamic matrix control consists of reference trajectory, predictive model, roll optimization and feedback correction and so on (Ran, 2004). Because of the algorithm is characteristics of online rolling optimization and feedback correction and it can timely make up for uncertainty that caused by the model mismatch and interference.

The system is the temperature and humidity coupling system of double input double output and it is shown in Fig. 3 (Huang, 2011; Zhang *et al*., 2012). T_{SP} and H_{SP} express value of the temperature and relative humidity, respectively, ΔU_1 is control increment of channel 1 (temperature channel), ΔU_2 is control increment of channel 2 (humidity channel); $A_{ij}(i, j = 1, 2)$ express coupling step model between channel *j* and channel *i*. y_T and y_H express the actual temperature and humidity value.

In order to eliminate the influence of channel 2 to channel 1, the interactions influence among n channel were eliminated according to the prediction compensation thought. According to the channel 1, the optimal control law after the compensation was given by the single variable DMC algorithm (Wang, 2001) and it was calculated as followed:

$$J_{1p}(k+1) = A_{11}\Delta U_1(k) + A_{011}U_1(k-1) + A_{12}\Delta U_2(k) + A_{02}\Delta U_2(k-1) + h_1 e_1(k) \tag{1}$$

The single variable DMC was expanded into multivariate DMC and the control law was calculated as followed (Chalabi *et al*., 2002):

$$Y_{p1}(k+1) = A_{11}\Delta U_1(k) + A_{011}U_1(k-1) + A_{12}\Delta U_2(k) + A_{012}U_2(k-1) + h_{11}e_{11}(k) + h_{12}e_{12}(k) \quad (2)$$

Supposed that:

$$h_{11} = h_{12} = h_1, \; e_1(k) = e_{11}(k) + e_{12}(k)$$

And it was obtained:

$$h_{11}e_{11}(k) + h_{12}e_{12}(k) = h_1(e_{11}(k) + e_{12}(k)) = h_1e_1(k) \quad (3)$$

where,

$$e_1(k) = y_1(k) - [y_{m11}(k) + y_{m12}(k)$$

The target of DMC control algorithm that calculate the actuator control quantity according to the deviation of output predicted value and output expectations, so that the output of the object close to the desired reference trajectory as much as possible. In order to achieve this goal, it is need to find an index to express the above characteristics, that is to say, the objective function and the optimal control law was obtained. The optimization goal of function is that the sum-of-squares differences between prediction output value and the reference trajectory is minimum in the selected time domain (Li, 2007). The optimal control law was calculated according to the quadratic performance indicators as followed:

$$J_{1P} = [Y_{1P}(k+1) - Y_{1r}(k+1)]^T Q_1 [Y_{1P}(k+1) - Y_{1r}(k+1)] + \Delta U_1^T(k)\,\lambda_1 \Delta U_1(k) \quad (4)$$

where,

$$Y_{1r}(k+1) = [y_{1r}(k+1), y_{1r}(k+2), \ldots\ldots, y_{1r}(k+p)]^T$$

The performance indicators in (4) were optimized, according to $\partial J_P / \partial \Delta U_1(k) = 0$ and (4), $\Delta U_1(k)$ was calculated as followed:

$$\Delta U_1(k) = (A_{11}^T Q_1 A_{11} + \lambda_1)^{-1} A_{11}^T [Y_{1r}(k+1) - A_{011}U_1(k-1) - A_{012}U_2(k-1) - A_{12}\Delta U_2(k) - h_1e_1(k)] \quad (5)$$

In a similar way, $\Delta U_2(k)$ was calculated as followed:

$$\Delta U_2(k) = (A_{22}^T Q_2 A_{22} + \lambda_2)^{-1} A_{22}^T [Y_{2r}(k+1) - A_{022}U_2(k-1) - A_{021}U_1(k-1) - A_{21}\Delta U_1(k) - h_2e_2(k)] \quad (6)$$

It is shown in (5) and (6) that $\Delta U_1(k)$ and $\Delta U_2(k)$ are mutually compatible, to facilitate the calculation, supposed that:

$$\begin{cases} T_1 = (A_{11}^T Q_1 A_{11} + \lambda_1)^{-1} A_{11}^T \\ T_2 = (A_{22}^T Q_2 A_{22} + \lambda_2)^{-1} A_{22}^T \\ H_1 = Y_{1r}(k+1) - A_{011}U_1(k-1) - A_{012}U_2(k-1) - h_1e_1(k) \\ H_2 = Y_{2r}(k+1) - A_{022}U_2(k-1) - A_{021}U_1(k-1) - h_2e_2(k) \end{cases} \quad (7)$$

(7) Substituted for (5) and (6), $\Delta U_1(k)$ and $\Delta U_2(k)$ were calculated by solving as followed:

$$\begin{cases} \Delta U_1(k) = [I_1 - T_1A_{12}T_2A_{21}]^{-1}[T_1H_1 - T_1A_{12}T_2H_2] \\ \Delta U_2(k) = [I_2 - T_2A_{21}T_1A_{12}]^{-1}[T_2H_2 - T_2A_{21}T_1H_1] \end{cases} \quad (8)$$

It does not exist cross coupling between $\Delta U_1(k)$ and $\Delta U_2(k)$. $U_1(k)$ and $U_2(k)$ were calculated as followed:

$$U_i = U_i(k-1) + \Delta U_i(k) \quad (9)$$

When the temperature and humidity conditions in system have great changes, the model will be serious mismatch and the control accuracy is serious loss. It have shown in trials that the stability value of the temperature and humidity is unable to achieve the set value due to fixed DMC parameters when the temperature and humidity condition have great differences, Because the set value of the temperature and humidity is changed, the model is also changed and the prediction model and the actual model are mismatch. If we still adopt fixed decoupling parameters to control, when the model mismatch is more serious and the control accuracy is serious loss. In order to prevent the above phenomenon in the different conditions, on the basis of the traditional DMC decoupling algorithm and the adaptive algorithm is embodied, the principle diagram is shown in Fig. 4. $\Delta U_1(k)$ and $\Delta U_2(k)$ were calculated by weighted as followed:

$$\begin{cases} \Delta U_1(k) = [I_1 - T_1(\beta_2A_{12})T_2A_{21}]^{-1}[T_1H_1 - T_1(\beta_2A_{12})T_2H_2] \\ \Delta U_2(k) = [I_2 - T_2(\beta_1A_{21})T_1A_{12}]^{-1}[T_2H_2 - T_2(\beta_1A_{21})T_1H_1] \end{cases} \quad (10)$$

where, β_1 is weight that the temperature has influence on humidity in humidity control, the bigger its value is, the greater the influence on humidity is. The meaning of β_2 is similar to β_1. When $\beta_1 = \beta_2 = 0$, it means that the coupling relationship does not exist between the temperature and humidity channel. When $\beta_1 = \beta_2 = 1$, the decoupling algorithm doesn't join the adaptive algorithm. The decoupling is realized through the real-time control decoupling factor β_1 and β_2 values under different working conditions. We take heating as an example, the concrete control methods were calculated as followed:

$$\begin{cases} \text{if } e_t \succ 0, \text{and } {de_t}/{dt} \geq 0, \text{so } \beta_2 \uparrow \\ \text{if } e_t \succ 0, \text{and } {de_t}/{dt} \prec 0, \text{so } \beta_2 \downarrow \end{cases} \quad (11)$$

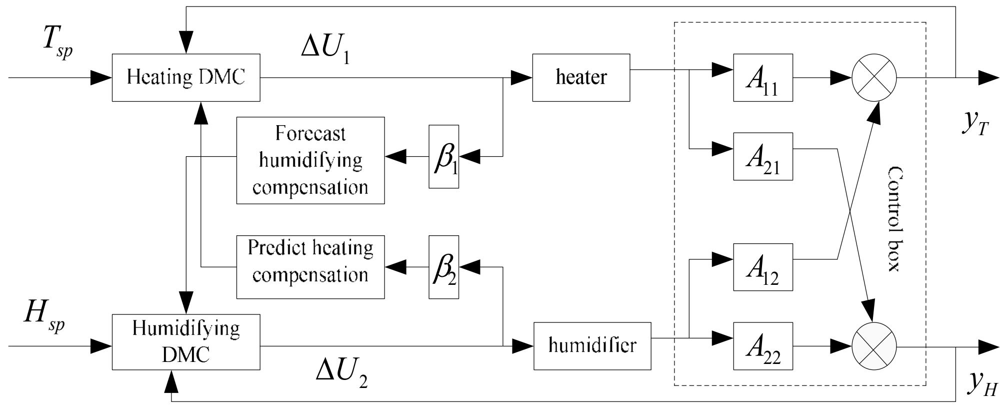

Fig. 4: Adaptive DMC decoupling principle diagram

where,

$$e_t = T_{sp} - y_T$$

The $\beta_2\downarrow$ indicates that β_2 reduce by 0.1 on the basis of the last value and the $\beta_2\uparrow$ indicates that β_2 increase by 0.1. The initial value of β_2 is 1 and $0\leq \beta_2\leq 2$, when the value of β_2 increase to the maximum, if the conditions are still met and it is no longer increased. By the same token, when the value of β_2 reduce to the minimum and it is no longer reduced. $\beta_2\uparrow$ and $\beta_2\downarrow$ are the opposite, the adjustment method of β_1 is the same as β_2.

The proposed adaptive DMC decoupling control algorithm process is as follows.

Step1: Supposed that the initial value of T_{SP}, H_{SP}, β_1 and β_2 is 1.
Step2: The actual output of cycle sampling is y_T and yH and the error and the corresponding error rate are obtained.
Step3: β_1 and β_2 are adjusted according to the adaptive algorithm.
Step4: According to (8), the control output $\Delta U_1(k)$ and $\Delta U_2(k)$ are obtained at the k time.
Step5: Supposed that $k = k+1$, If T_{SP} and H_{SP} are invariant, then turned to Step2, or turned to Step1.

RESULTS AND DISCUSSION

Model identification is the output response of the acquisition controlled object under the artificial input signal, or input and output data-recording in the system normal operation, it is necessary for measurement results to data processing or mathematical calculation by a certain means, so as to estimate the mathematical model of the object. The dynamic characteristics of the object are included in changing input/output data, so it can establish mathematical model by containing information of the input/output data.

When humidity is stability, the step control signal is inflicted in the humidifier and the heater does not inflict any signal. The humidity step response coefficient in system is measured by humidity sensor in each moment and the humidity step response coefficient is measured by humidity sensor in each moment. The choice of data is uniform, the abnormal data is filtered at the same time and the main information of dynamic response process in system is extremely included in data. According to the transfer function of step response identification system (Zhang and Zhang, 2009), the fitting curve of selected data, first order transfer function and second order transfer function are shown in Fig. 5. It was shown in Fig. 5 that the actual model was close to the second order model, so as to the step response model of humidity was calculated in humidifying as followed:

$$A_{22} = \frac{32}{10.32s^2 + 6.214s + 1} \tag{12}$$

The step control signal is inflicted in the heater by using the same method, the control signal of humidifier is zero and the temperature response data can be measured. The curve that was shown in Fig. 6 can be obtained by the same method of data processing and the heating temperature model was calculated as followed:

$$A_{11} = \frac{12.81}{190.3S + 1} \tag{13}$$

When the step control signal is inflicted the heater, the step response data of temperature is measured by temperature sensor and the step response data of humidity is measured by the humidity sensor. The temperature response data also is measured by temperature sensor in humidifying, according to the data, the corresponding step response model curve was obtained, it was shown in Fig. 7 and 8, the second order transfer function model was calculated as followed:

$$A_{21} = \frac{-21.95}{25.14s + 1} \tag{14}$$

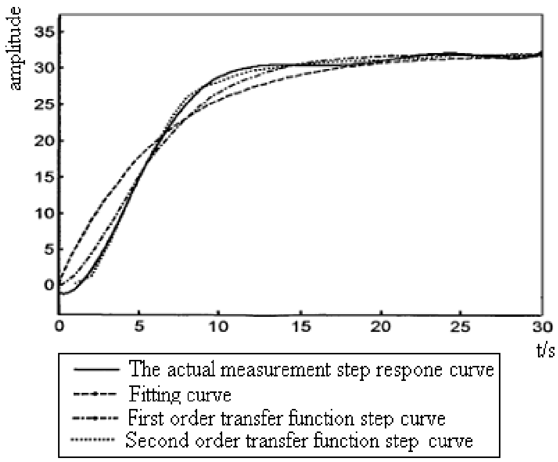

Fig. 5: The humidity step response model curve in humidifying

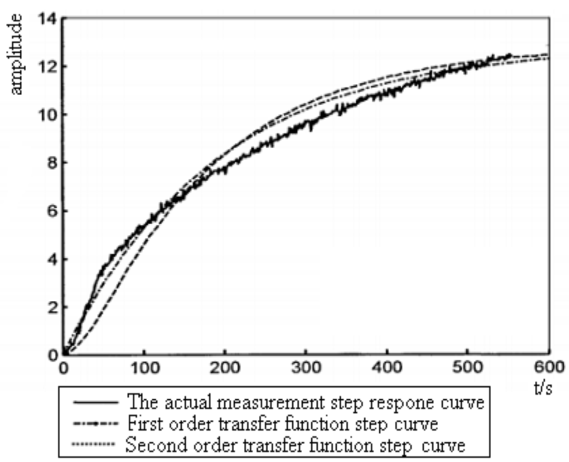

Fig. 6: The temperature step response model curve in heating

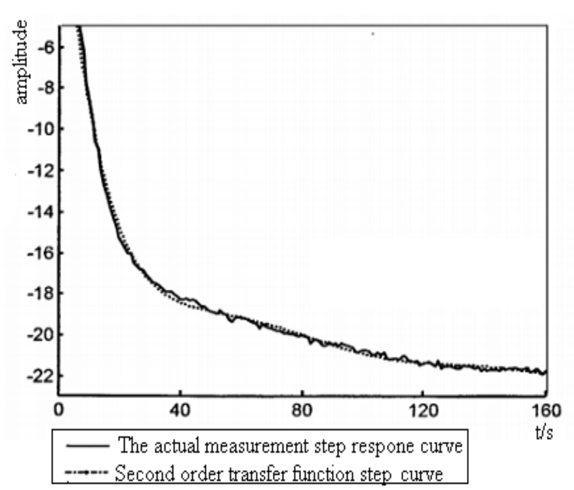

Fig. 7: The step response model curve of humidity in heating

$$A_{12} = \frac{-1.093}{3.918s^2 + 5.31s + 1} \tag{15}$$

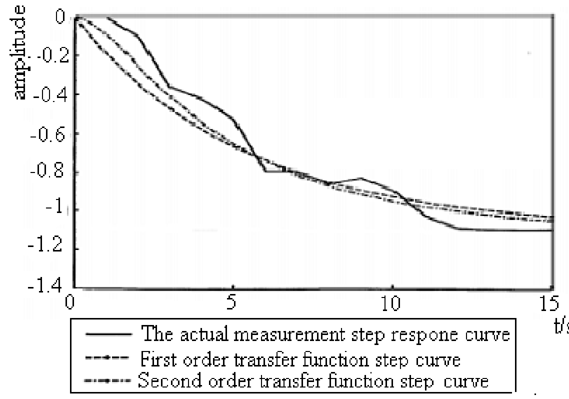

Fig. 8: The step response model curve of humidity in humidifying

According to the obtained mathematical model as the above and the simulation was done in Matlab7.0 platform, the PID control system was built by Simulink and its simulation response curve was shown in Fig. 9, The corresponding parameter value is $K_{1p} = 15$, $K_{1i} = 4$, $K_{1d} = 0$ and $K_{2p} = 10$, $K_{2i} = 1$, $K_{2d} = 0$. The DMC simulation system was built by MPC toolbox , the simulation response curve was shown in Fig. 10, the corresponding simulation parameters is P = 10 (predict step) and M = 5 (control step). It was shown in Fig. 10 that temperature and humidity have reached stable when t = 30, at this time, the set value of the temperature vary from 30 to 40°C and humidity value has slight decrease, but it quickly return to the set value. When t = 70, the temperature has already been stable, then the set value of humidity vary from 40 to 80%, the humidity quickly reached a new value and the temperature return to the set value in the humidity rise process after the temperature dropped slightly.

It was shown in Fig. 9 and 10 that the overshoot of prediction decoupling algorithm was greatly reduced and can effectively weaken dynamic coupling between temperature and humidity and the static coupling was eliminated at the same time. Moreover, in steady state, the temperature and humidity control precision is very high and the shock phenomenon won't be produced too. Although the regulation time of the DMC algorithm increased, but the overshoot is very small, the changes of temperature and humidity are gentle. The simulation results shown that the system control accuracy requirement can be obtained.

In order to validate the effectiveness of the proposed algorithm, the experiment was done on the basis of built system. Due to the PID control is simple in structure, it is easy to be realized and it has high reliability and it has widely application in the actual engineering, so we take the classical PID control algorithm as a contrast test. First of all, the incremental PID control procedures was written by VB, the dynamic coupling operation curve of temperature and

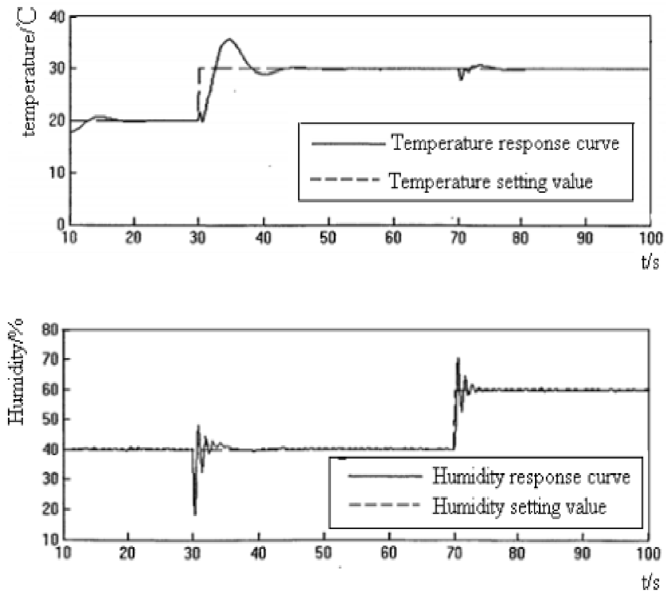

Fig. 9: PID simulation response curve

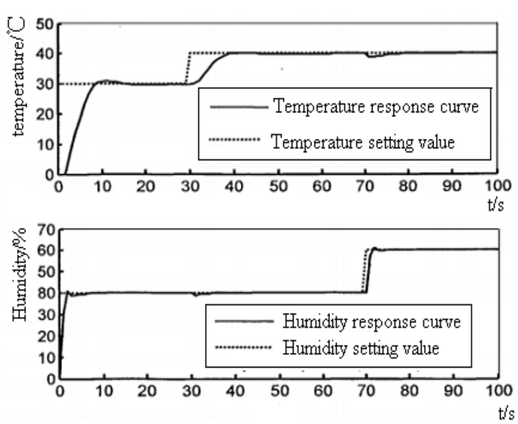

Fig. 10: Adaptive DMC decoupling algorithm simulation curve

humidity was obtained, the incremental PID algorithm was shown in Fig. 11 and the operation curve was shown in Fig. 12. Then, the adaptive DMC decoupling algorithm procedures was written on the basis of the single variable DMC and the corresponding PC monitoring interface was designed, the heating channel and humidifying channel operation curve were obtained, the adaptive DMC decoupling algorithm was shown in Fig. 13 and the operation curve was shown in Fig. 14.

It was shown in Fig. 12 and 14 that the fluctuations of temperature and humidity that were controlled by PID were much bigger, especially humidity. In the process of warming, the fluctuates of humidity controlled by PID were significantly faster, the humidity controlled by adaptive DMC algorithm declined, but it quickly returned to the set value, so it is

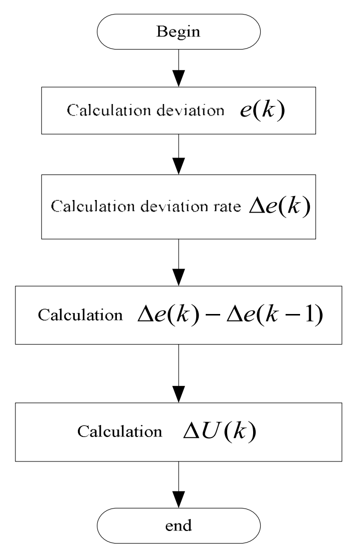

Fig. 11: The incremental PID algorithm flow chart

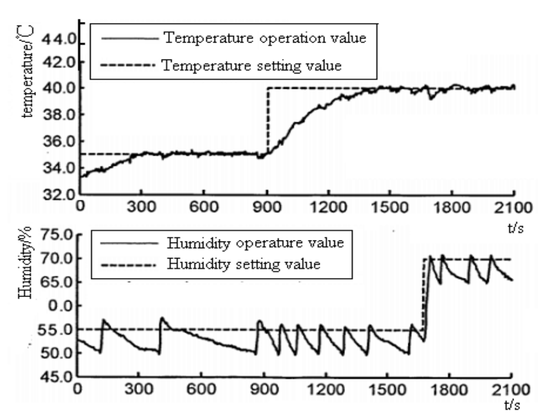

Fig. 12: PID control operation curve

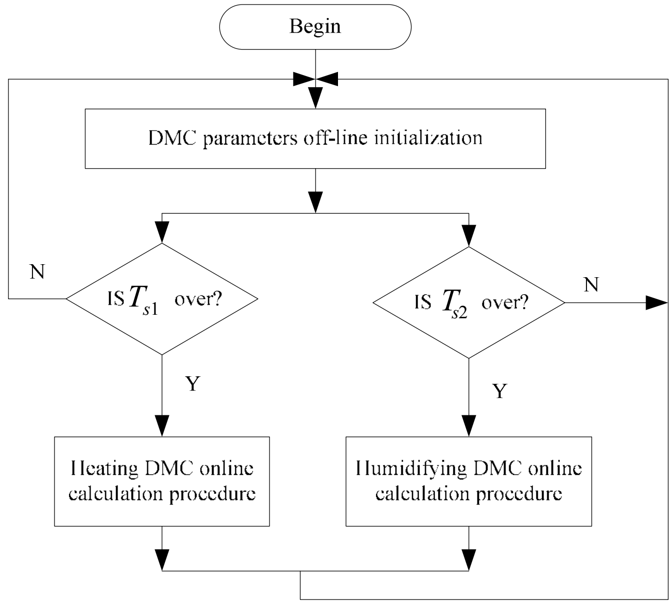

Fig. 13: Adaptive DMC decoupling algorithm flow chart

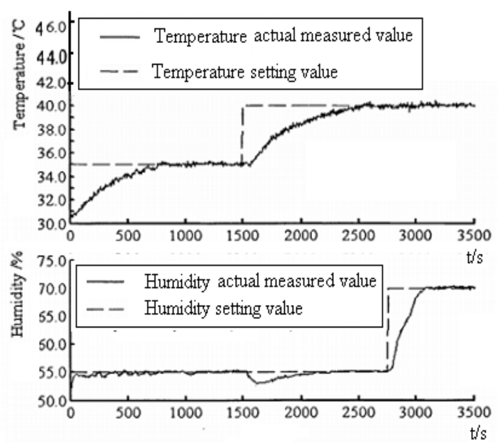

Fig. 14: The temperature and humidity operation curve of adaptive DMC decoupling

a strong dynamic decoupling ability. In the process of humidifying, the temperature controlled by PID suffered a mild decline and the temperature controlled by adaptive DMC remain unchanged and it explain that the temperature controlled by adaptive DMC is not easy to be interference by humidity, it has strong stability. When the temperature and humidity is stability, the fluctuation range of temperature controlled by PID is about ±0.4°C and the relative humidity is ±4.8%. And the fluctuation of temperature controlled by adaptive DMC algorithm is ±0.2°C and the humidity is ±0.5%. So, in static decoupling aspects, the adaptive DMC decoupling algorithm also has a lot of advantages. In temperature control, two control methods are superior control performance. But in the humidity control, the adaptive DMC is better than PID control. From the transfer function model, it is known that the humidity model is second order, for second order model control, PID control exist oscillation and the adaptive DMC algorithm does not exist the problem, even the model produce mismatch, the requirement of accuracy can be met too. In order to prevent the generation of overshoot, at the price of rapidity in adaptive DMC, whether the rise time of temperature or the rise time of humidity are greater than PID control. Due to the requirements of the time is not very strict, the control time of temperature and humidity is able to meet the practical requirements.

CONCLUSION

This study studied the dynamic coupling characteristics of temperature and humidity and put forward adaptive DMC decoupling control strategy that is easy to be realized in the project. The cross influence between two channel was eliminated by prediction feed-forward compensation method and the dynamic and static decoupling between temperature and humidity were realized. The online optimization of decoupling parameters was realized by adaptive decoupling algorithm, in order to prevent from reducing the control accuracy due to serious mismatch under different conditions. Compared with the traditional PID control method, the adaptive DMC decoupling algorithm has good dynamic decoupling ability and the system stability is much higher, robustness is much stronger, the adaptive ability is very good.

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