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[1, 2]Mingge Wu
[1, 2]Hua Xiao
[2]Chengji Lu
[2]Minkai Zhang
[2]Jiangcheng Jin
[1, 2 *]Xiaowen Xie

Research on decoupling greenhouse temperature and humidity based on feedback linearization

Abstract: -.In order to improve the control effect of each environmental factor of conventinal glasshouse, a realistic nonlinear glasshouse system feedback linearization decoupling control arithmetic has been reported. The multi-input, multi-output system which is nonlinear is turned into two detached single-input, single-transport stepwise linear systems by implementing the encoder algorithm, and the relation of the ambient components, which is strong coupling, such as the temperature and humidity, is alleviated. The simulation results show that if the target value of the environmental factor is within a proper controllable range, the controlled system of greenhouse temperature and humidity can achieve a good following effect, eliminate the coupling between temperature and humidity, and improve the accuracy of temperature and humidity control, which can effectively reduce energy consumption and improve the comprehensive benefit of greenhouse production. Precision of temperature and humidity control, which can effectively reduce energy consumption and improve the comprehensive benefits of greenhouse production.

Keywords:Greenhouses; Temperature and humidity; Feedback linearization; Decoupled control.

I. INTRODUCTION

Greenhouse is considered as one of the best technologies for agriculture as it allows for counter-seasonal growth of crops, improves the quality and quality of crops and artificially controls the environment in which the crops are grown.Greenhouses, as a type of smart agriculture, are widely recognized as an alternative to the reduction of arable land area and are one of the options for sustainable development and facility-based agriculture.Greenhouse environmental control and monitoring is considered to be one of the largest and most promising technologies for realizing greenhouse economies of scale.In the control process, environmental factors such as temperature, humidity, carbon dioxide concentration and light intensity are characterized by nonlinearity, strong coupling, time lag and other characteristics that adversely affect the control of the greenhouse environment, while the two environmental factors of temperature and humidity in the greenhouse are the two most important environmental factors affecting the growth of greenhouse crops.Therefore, decoupling of temperature and humidity in greenhouses is crucial in industry.Conventional decoupling techniques in industry, such as the diagonal matrix method and feed-forward compensated decoupling, consume high energy costs and lead to large controller sizes.In contrast, the feedback linearization decoupling technique is currently considered a better alternative due to its simplicity of operation, low investment cost and compactness.

In the design of the controller, due to the existence of temperature and humidity environmental factors in the greenhouse nonlinear, time lag, strong coupling, etc., the establishment of its accurate mathematical model is extremely difficult, and the traditional PID control is difficult to achieve good control results.Therefore, the fuzzy control method has been introduced by many scholars into the traditional PID control, the PID parameters are rectified in real time by the fuzzy inference in the fuzzy controller, and the fuzzy PID control system is established, the mathematical model of this method does not need to be particularly accurate, and its stability is higher than that of the traditional PID control.However, in the greenhouse temperature and humidity in the actual control process there is an uncertain and complex process, and temperature and humidity environmental factors there is a strong coupling, temperature and humidity how to decouple control, greenhouse control system to optimize the control effect is also one of the hot spots of research.

Some researches and studies on decoupling control of greenhouse environment have been proposed by many researchers and research applications: Francisco GariasManas et al. proposed fuzzy decoupling control for decoupling control of greenhouse temperature and humidity.Can Liu et al. proposed the establishment of a polynomial data fitting method to compensate temperature and humidity, and designed a temperature and humidity decoupling controller.O Korner et al. proposed a system design scheme based on diagonal decoupling

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[1]College of Mechanical and Electrical Engineering, Wenzhou University, Wenzhou325035, China
[2]Institute of Laser and Optoelectronics Intelligent Manufacturing, Wenzhou University, Wenzhou325000, China
*Corresponding author: Xiaowen Xie
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for PI control of greenhouse temperature and humidity prediction to realize real-time control and decoupling of greenhouse temperature and humidity environmental factors.J.P. Coelho et al. proposed a PID neuron network algorithm based on particle swarm optimization algorithm to optimize the weights of the PID neuron network through particle swarm optimization algorithm to make the greenhouse system achieve the ideal decoupling effect.Andrzej Pawlowski et al. proposed a feed-forward compensation method to realize the decoupling of the two-dimensional variable system of temperature and humidity in greenhouse system.However, these decoupling methods are complex and computationally intensive and are not suitable for greenhouse production control.In this paper, feedback linearization decoupling is used for greenhouse internal temperature and humidity, the greenhouse system model is converted into a radioactive nonlinear model, the variables are decoupled by coordinate transformation and state feedback, and a PID controller is designed to simplify the system, so that the variables can track the set values effectively.

II. GREENHOUSE TEMPERATURE AND HUMIDITY CHARACTERISTICS

Temperature and humidity are the two most important environmental factors that affect the growth of crops inside the greenhouse, and the precise control of temperature and humidity not only affects the growth of crops, but also has a significant impact on the quality and quality of crops.According to the monitoring data inside the greenhouse, the greenhouse temperature and humidity interactions are very severe and adversely affect the greenhouse control system. Figures 1 and 2 show the temperature and humidity changes inside the greenhouse on March 10, 2023, respectively.

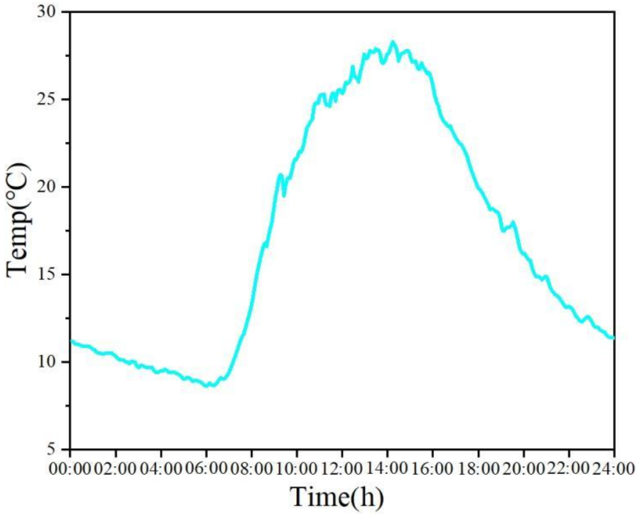


Figure 1. Temperature change on March 10

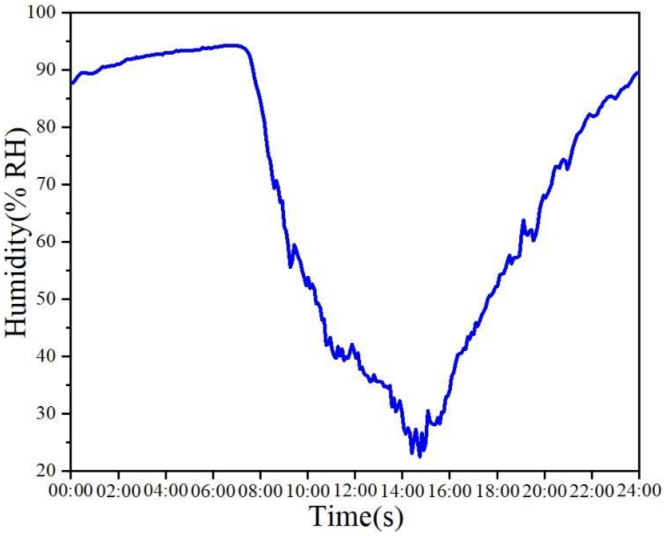


Figure 2. Changes in humidity on March 10

As can be seen from Figures 1 and 2, the temperature gradually decreased from 11.2°C to 8.6°C and the humidity gradually increased from 87.8% RH to 94.3% RH from 00:00 to 06:12 hours.The temperature gradually increased from 8.6 degrees Celsius to 28.3 degrees Celsius and the humidity gradually decreased from 94.3% RH to 23.1% RH between 6:12 and 14:02 hours.Temperature gradually decreased from 28.3°C to 11.2°C and humidity gradually increased from 23.1% RH to 89.8% RH between hours 14:02 and 24:00.It follows that when the temperature rises, the humidity decreases; when the temperature falls at the same time the humidity rises gradually.The strong coupling of the two environmental factors of temperature and humidity inside the greenhouse brings serious difficulties to the greenhouse control system, so it is necessary to decouple the greenhouse temperature and humidity to reduce the mutual influence between temperature and humidity, so that the temperature and humidity control effect is more favorable.

III. FEEDBACK LINEARIZATION DECOUPLING IN GREENHOUSES

A. Mathematical modeling of greenhouses

The statistical modeling of the dynamics of the greenhouse air heat and moment phase equilibrium is verified to be strongly delineated.By considering the control of revealed and potential incidence of heat and the balance calculus equity on the cubic meter volume of the room, the calculus equality is as follows:

$$\frac{dT_{in}(t)}{dt} = \frac{1}{\rho C_P V_T}\left[Q_{heater}(t) + S_i(t) - \lambda Q_{fog}(t)\right]$$

$$- \frac{V_R(t)}{V_T}\left[T_{in}(t) - T_{out}(t)\right] - \frac{UA}{\rho C_P V_T} \times \left[T_{in}(t) - T_{out}(t)\right. \qquad (1)$$

$$\frac{d\omega_{in}(t)}{dt} = \frac{1}{V_H}Q_{fog}(t) + \frac{1}{V_H}E\big(S_i(t), \omega_{in}(t)\big) - \frac{V_R(t)}{V_H}\left[\omega_{in}(t) - \omega_{out}(t)\right]\#(2)$$

where $T_{in}(t)$ denotes the room pressure (°C),$T_{out}(t)$ as ambient outdoor preference (°C),UA as the thermal transition factor ($W.K^{-1}$), ρ as density of space (1.2 $kg.m^{-3}$), C_P specific caloric of atmospheric air (1006$J.kg^{-1}.K^{-1}$),$Q_{heater}(t)$ denotes the volume of total heat (W) generated by the conservatory furnace,$S_i(t)$ represents the terrestrial radiant power (W) of the interval,$Q_{fog}(t)$ denotes the capacity of the mist regime ($g.H_2O.s^{-1}$),λ represents the potential energy of evolution (2257$J.g^{-1}$),$V_R(t)$ denotes amount of air flow ($m^3.s^{-1}$),$\omega_{in}(t)$ and $\omega_{out}(t)$ denote the ratio of inside and outside moistures (dried bag of air to total weight of moisture evaporation, $g.H_2O.s^{-1}$), $E\big(S_i(t), \omega_{in}(t)\big)$ denotes the vegetable transpiration forcing rate ($g.H_2O.s^{-1}$),V_T and V_H represent the amount of active blending for temp and hydrography.

B. Feedback linearization of greenhouses

Feedback linearization is an uncommon solver type of coupling mapping model found in factories, which transforms a baseline equation of condition from a linear position by combining vectorial coordinates, Laplace shift, and other transformations.From the preceding chapter on the statistical model of warmth and moisture in the hothouse, it can be argued that to achieve the feedback linearization of the hatchery, it is desirable to reduce the hothouse model in the foregoing article to an affine nonlinear model:

$$\begin{bmatrix}\dot{T}_{in}\\ \dot{\omega}_{in}\end{bmatrix} = f + G\begin{bmatrix}U_c\\ U_v\end{bmatrix}\#(3)$$

$$\begin{bmatrix}y_1\\ y_2\end{bmatrix} = \begin{bmatrix}T_{in}\\ \omega_{in}\end{bmatrix}\#(4)$$

where, $f = \begin{bmatrix}f_1\\ f_2\end{bmatrix}$, $G = [g_1 \quad g_2]$.

$$f_1 = \frac{c_{rad}}{C_P}V_{rad} - \frac{c_{aiou}}{C_P}(T_{in} - T_{out})\#(5)$$

where c_{rad} denotes the solar irradiation attributable heat load fraction,V_{rad} denotes external solar irradiance ($W.m^{-2}$) external to the glasshouse,c_{aiou} represents the amount of heat transferred by the capping board to the ambient heat source ($W.m^{-2}.$°C^{-1}).

$$f_2 =- \frac{c_{leak}}{c_{caph}}(\omega_{in} - \omega_{out}) + \frac{c_v\left(1 - e^{-c_{pld}X_d}\right)}{c_{caph}}\left[\frac{c_{v1}e^{\frac{c_{v2}T_{in}}{c_{v3}+T_{in}}}}{c_R(c_T + T_{in})} - \omega_{in}\right]\#(6)$$

where c_{leak} is the measure of cover board penetration level of air ($m.s^{-1}$),c_{caph} represents the hydrovapor content per cubic millimeters of vacuum per unit volume of air in the cryogenic chamber ($m^3.m^{-2}$), $c_{v1}e^{\frac{c_{v2}T_{in}}{T_{in}+c_{v3}}}$ represents the content of subsidized water evaporation ($kg.m^{-3}$) at canal surface temperature at T_{in},c_v equals the transfer factor ($m.s^{-1}$),c_{v1} ($J.m^{-3}$), c_{v2} and c_{v3} (°C) parameterizing pressure of saline solvent in saturated vapor, c_R as the constant of the gas $(J.K^{-1}.mol^{-1})$, c_T shows the position of the temperature (K) at 0°C.

$$g_1 = [g_{11} \quad g_{21}]^T = \begin{bmatrix} \frac{1}{c_p} & 0 \end{bmatrix}^T \#(7)$$

$$g_2 = [g_{12} \quad g_{22}]^T = \begin{bmatrix} -\frac{c_{capv}(T_{in} - T_{out})}{c_p} & -\frac{\omega_{in} - \omega_{out}}{c_{caph}} \end{bmatrix}^T \#(8)$$

To determine the phase sequence of the hothouse system, in this center of the model, the relative order of the matrix $A(x) = \begin{bmatrix} L_{g1}h_1(x) & L_{g2}h_1(x) \\ L_{g1}h_2(x) & L_{g2}h_2(x) \end{bmatrix}$ is non-singular, so the phases of the pulse of the energy system are $r_1 = r_2$ for each output, and the frequency of the phases of the system is $r = \sum_{i=1}^{2} r_i = 2$, this means that the screen can be undecoupled with feedback linearization for control.The coordinate changes are as shown below:

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \begin{bmatrix} h_1(x) \\ h_2(x) \end{bmatrix} = \begin{bmatrix} T_{in} \\ \omega_{in} \end{bmatrix} \#(9)$$

The calculation of the control parameters is as shown below:

$$\begin{bmatrix} U_q \\ U_v \end{bmatrix} = A^{-1}(x)\left(-b(x) + \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}\right) = G^{-1}\left(-f + \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}\right) \#(10)$$

In this case the hothouse system of environments is linearized and uncoupled by the implemented support of the introduced control $v = [v_1 \quad v_2]^T$.

Based on the coupling function of the decoupled system, we place two PID controllers to handle the various aspects of the control of the decoupled variables, and the resulting system structure is shown in Figure 3.

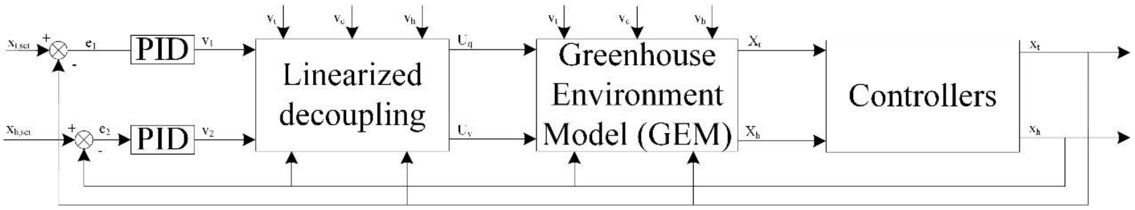
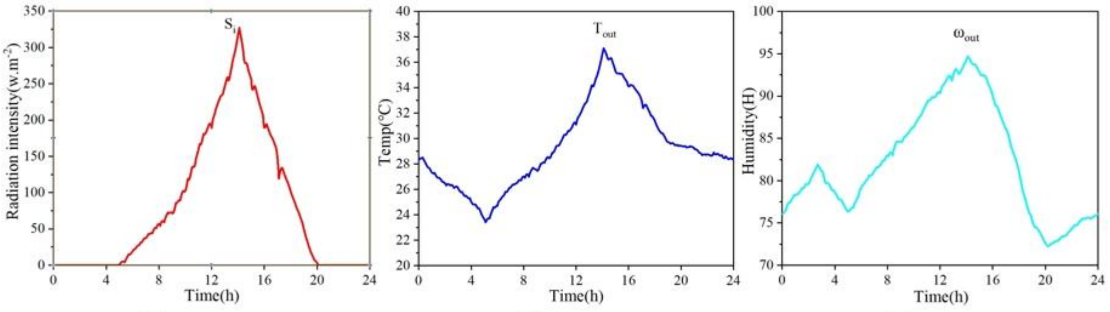


Figure 3. System Block Diagram

The control sequence is as below: the input of the state vector in the hothouse is feedback to the input of the system, the factual export of the variable is matched with the respectable speed control point to receive the mistake point, which is used as input to the PID controller, and then the value of the control variable v is supplied as the input to the linearization decoupling algorithm.The activator control parameters are then evaluated and implemented in the hothouse surroundings, and the integrals control block is then used to create the state parameter.

IV. RESULTS AND DISCUSSION

The realistic simulation exercise chose the warm climate of Wenzhou area on a solstice day in winter, and the three perturbation drivers, v_c, v_t, and v_h, are plotted in figure 4. In the figure, S_i is the radiant solar intensity incoming into the cabin, the shaded curtains are driven from 8:00 a.m. to 16:00 p.m., T_{out} denotes the outer surface temperature, and ω_{out} is the outer surface humidity.



(a) v_c (b) v_t (c) v_h

Figure 4. Extra-greenhouse perturbation factor

Devise a final maximum draught percentage of $0.143m^3.m^{-2}.s^{-1}$,the largest spray depuration occurred at a rate of 15 $kg.m^{-2}.d^{-1}$, which is approximately 10.42 $g.m^{-2}.min^{-1}$,suppose the hysteresis time of the temperature and humidity inductor is 0.2min, the typical system time constant is greater than 4 times the hysteresis time can be taken, taking into consideration that the glasshouse is a large inertia chain, the bigger inertia time normal, the thermal and moisture dynamic fast response pace does not take too much time, can leave some margin, take the bigger time nanoscale, take $\tau_1 = \tau_2 = 5$min.

The building of the simulation model in MATLAB according to figure 3, in the simulation model, the default temporary temperature is kept as 0℃, the required target as 25℃, the default humidity is kept as 60%RH, the required target as 90%RH, and the simulation time is kept as 8600s.The controllers are designed as two types of PID controllers and fuzzy PID controllers and the simulation results of these two controllers are compared and the simulation results are shown in figure 5 and figure 6.

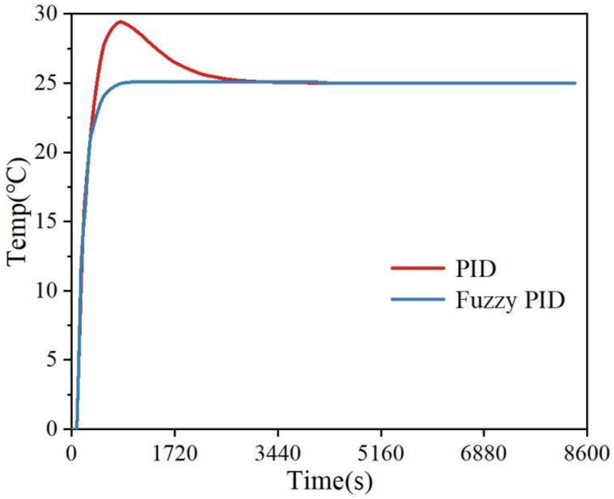


Figure 5. Temperature simulation results

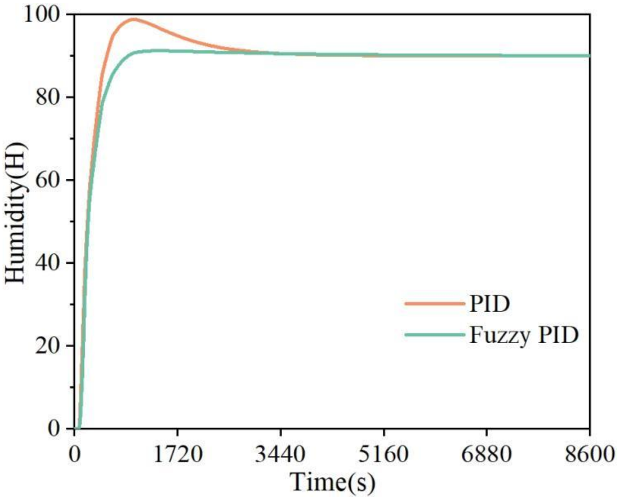


Figure 6. Humidity simulation results

Table .1 Temperature and humidity simulation results

Environmental factor	Controller	Overshoot	Accommodation time
Temp	PID	17.6%	3600s
	Fuzzy PID	1.2%	2800s
Humidity	PID	29%	4900s
	Fuzzy PID	4%	3200s

As can be seen from figure 5 and figure 6, when the temperature rises, the humidity rises with it, then the coupling phenomenon between the temperature and humidity environmental factors inside the greenhouse is mitigated by using the feedback linearization, and according to table 1, it can be seen that the temperature reaches the maximum overshooting amount of 17.6% at 1000s and reaches the stabilizing effect at 3600s when the PID controller is used, and the humidity reaches the maximum overshooting amount of 29% at 1100s, and reaches the stabilizing effect at 4900s; when using fuzzy PID controller, the temperature reaches the maximum overshooting amount of 1.2% at 1400s, and reaches the stabilizing effect at 2800s, and the humidity reaches the maximum overshooting amount of 4% at 1300s, and reaches the stabilizing effect at 3200s. It can be seen that the decoupling effect of the greenhouse temperature and humidity environmental factors is achieved by using feedback linearization, and the controller can achieve good control effect when using fuzzy PID controller.

V. CONCLUSION

For the nonlinear and highly coupled greenhouse system, the feedback linearization decoupling method can effectively lift the strong coupling relationship between temperature and humidity, and transform the system into an independent SISO linear system that is easy to control with classical control methods. If the set value is within a reasonable controllable range, the two-factor coordinated control of temperature and humidity of greenhouse system can achieve a good following effect.Simulation experiments are based on an accurate mathematical model, because the simulation model is only an approximate mathematical model of the actual greenhouse system, the actual system is not possible to obtain 100% decoupling effect, but at least it can significantly reduce the coupling between temperature and humidity, improve the accuracy of the temperature and humidity control, thus effectively reducing energy consumption and improving the comprehensive benefits of greenhouse production.

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