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Original Research Paper

Simulation and Fuzzy Control of Greenhouse Microclimate Based On Simulink

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ABSTRACT

This paper deals with the problem of controlling greenhouse environment defined by the temperature and humidity. According to the thermal balance principle and water vapour quality balance principle of greenhouse, two non-linear differential models each for air temperature and humidity inside greenhouse were constructed. The corresponding fuzzy controller for greenhouse environment was set up by using the ANFIS tools of MATLAB, including the choosing of variables, quantification of the domain, definition of fuzzy sets, choosing of membership functions and controller training. After the combination between controller and the controlled object by Simulink, simulation was carried out to analyse the performance of control system. The simulation results testify the validity and reasonability of the fuzzy control strategy for the environment control in the greenhouse, and the achievement has certain reference value for the development in intelligent control of the greenhouse microclimate.

INTRODUCTION

The greenhouse vegetable cultivation mode develops very fast in China at present in which ventilation is widely used as main method of indoor cooling and moisture exhausting. Obviously, it becomes the critical important and key link to do real-time and accurate ventilation to the greenhouse climate control.

The microclimate of greenhouse is such a non-linear, multivariable with strong coupling system that it is impossible to carry out ventilation management accurately if only controlled manually. In recent years, peoples have turned eyes to the investigation about smart control (Jeon & Tian 2009, Shen et al. 2011) where fuzzy control theory is widely used to control temperature and solve fuzzy problems (Ding et al. 2009). In the past, the fuzzy rules are usually set under personal experience. Therefore, the control result is always affected by subjectivity (Chen et al. 2011, Mellit & Kalogirou 2011, Noori et al. 2010, Wang & Li 2010). In the meanwhile, the research on microclimate of greenhouse abroad is usually simulated temperature and humidity separately and lack of integrative analysis of them together. So it is not widely used and developed in China because of its regionalism and limitations (Meng et al. 2009). Aiming at above problems resolution, this research is focus on temperature and humidity environment simulation control which is realized through real-time and precise control of air vents' open degree. Firstly, through the theory of model construction, the calculation model of temperature and humidity in greenhouse were established. Then based on ANFIS toolbox, the neural fuzzy controller with trapezoid membership functions was designed. Finally it realized the simulation of greenhouse environment control effect, by accomplishing the combination of controller and environment model. The test result is of high value to greenhouse intelligent control development.

MATERIALS AND METHODS

Test situation: The test was taken in E-Zhou Water-saving Irrigation Demonstration Base (114.52°E, 30.23°N) in 2011, Hubei Province, China. The north-south-oriented greenhouses built here have an average height 2.5m (maximum 3.2m), and the arch-shaped roof had an average roof angle of 27.5°. Each greenhouse volume was 1605.4m^2 and the covering (sidewalls and roof top) surface area was 1015m^2. The windows in the roof and sides were used to ventilate. The research object is tomato and the research is carried out during tomato season.

The test data includes the total radiation outside [R_a/(w/m^2)], outdoor air temperature [T_o/(°C)], outdoor relative humidity [RH_o/(%)], wind speed [v/(m/s)], which are all collected automatic by small outdoor weather station. Temperature on cover film inside [T_c/(°C)] is collected by corresponding sensor on LPS-05 type plant growth detecting instrument; soil water consumption [θ_i/(%)], measured by TDR; the open degree of vents, u=[0, 1, 2], where 0-no ventilation, 1-open skylights only, 2-skylights and side windows open at the same time. Indoor temperature [T_i/(°C)] and indoor relative humidity [RH_i/(%)] are collected by LPS-05 plant growth detecting instrument.

The test period is 7:00-18:30 per day and all the data are collected every 30mins. Although there are too many samplings, it would be enough to only collect two kinds of data, one in sunny day and the other in rainy day for they are two representative climates. The evaluation and simulation are based on the data of April 20th and April 21st (sunny and rainy, representative).

The greenhouse heat balance model: According to the principle of greenhouse thermal equilibrium and stability of the state, a greenhouse dynamic mathematical model was set up (Wu et al. 2007, Li et al. 2005, Wang et al. 2008).

$$\Delta Q = Q_{rad} - Q_{vent} - Q_{cac} - Q_{crad} \quad ...(1)$$

Where, Q_{rad}-sun radiation; Q_{crad} - longwave radiation loss; Q_{cac} - heat conduction loss; Q_{vent} - ventilation heat loss. That is,

$$V\rho c_p \frac{dT_i}{dt} = A_s R_a \tau_a - \frac{G_v(c_p\rho)(T_i - T_o)}{3.6} - \varepsilon_{12} A_c \sigma (T_i^4 - T_o^4) - A_c K_g (T_i - T_o) \quad ...(2)$$

Among them, τ_a - transmittance of plastic film, 0.75; A_s - greenhouse ground surface area, 584 m^2; A_c - the covering (sidewalls and roof top) surface area, 1015 m^2; T_i - the indoor temperature, K; T_o - outdoor temperature, K; V - greenhouse volume, 1605.4 m^3; c_p - indoor air specific heat, 1006, j/kg/K; ρ - indoor air density, 1.16 kg/m after; G_v - indoor and outdoor ventilation rate, m^3/s; ε_{12} - surface emissivity, which can be calculated by ε_1 and ε_2 (the emissivity of coating and air), ε_{12}= $(\varepsilon_1^{-1}+\varepsilon_2^{-1}-1)^{-1}$; σ - Stefan Boltzmann constant, 5.67×10^{-8}w/m^2/K^4; K_g - cover material heat transfer coefficient, $1.86^3\Delta T^{0.33}$ w/m^2/K.

Air moisture balance model: Assume the greenhouse air is a uniform distribution of ideal fluid, indoor dynamic moisture balance equation can be represented as follows (Wang et al. 2008, Fatnassi et al. 2009):

$$\Delta W_i = W_{ET} - W_v - W_c \quad ...(3)$$

Where, W_{ET} - soil water evaporation and plant transpiration; W_c - water vapour condensation inside roof cover film; W_v - the ventilation loss. That is,

$$h\frac{d(A_cH_i)}{dt} = \frac{\Delta\theta_i}{1800} - \frac{\rho c_p G_v(\frac{A_cH_i \cdot T_i}{2165} - e_{oa} \cdot RH_o\%)}{0.00163P \cdot A_c}$$
$$-0.00164(\frac{A_c}{A_s})[T_i(1+0.000175\frac{A_cH_i \cdot T_i}{P})$$
$$-T_c(1+0.378\frac{e_{ia}\cdot 100\%}{P})]^{\frac{1}{3}}(A_cH_i - \frac{2165e_{ca}}{T_c}) \quad ...(4)$$

Among them, h - the average height of greenhouse, m; AHi - indoor air absolute humidity, kg/m^3; RHo - outdoor air relative humidity, %; $\Delta\theta_i$ - soil moisture content change; e_i,e_o - indoor and outdoor actual water vapour pressure, kPa; e_{ia} – saturated air vapour pressure in greenhouse, kPa; e_{ca} - saturated vapor pressure of greenhouse covering film with the inside temperature of Tc, kPa; P - standard atmospheric pressure, 101.1 kPa; Other parameters are same as the above.

Simulink model: As shown in (2) and (4), the mathematical model of controlled object includes two nonlinear differential equations, which are related to each other so much, with a complex relationship between the variables, that the direct calculation is difficult. In this paper, based on the idea of sub modular design, the functions (2) and (4) were represented as a Simulink block diagram using Simulink toolbox, shown in Fig. 1.

As shown in Fig. 1, this block diagram has one input (the controlling ventilation rate Gv) and two outputs (Ti, RHi). The sub modules (Qrad,Qvent,Qcac,Qcrad,detaQ) and (W-ET,W-v,W-c,detaW) are respectively established, ac-

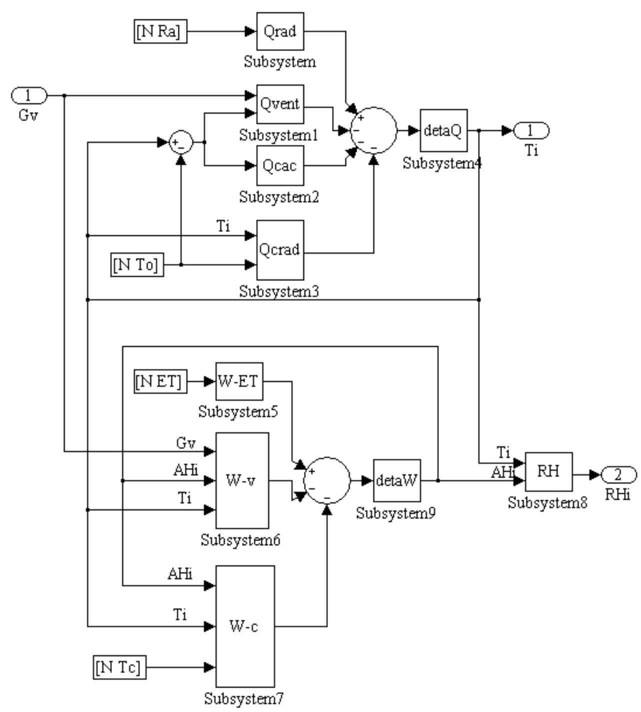


Fig. 1: Indoor temperature model of greenhouse.

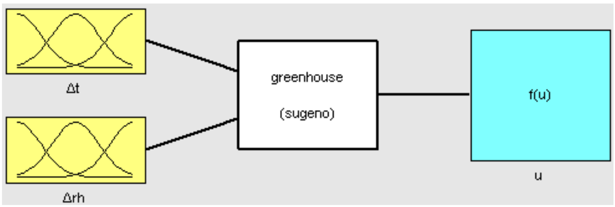


Fig. 2: Fuzzy controller structure.

cording to the function (2) and (4).

Design of fuzzy controller: This paper used a fuzzy system in the type of Takagi-Sugeno to realize the adaptive neural fuzzy controller design. As shown in Fig. 2, this is a two dimensional fuzzy controller, with dual inputs and single output, which selected the temperature deviation (*Δ*t) and deviation humidity (*Δ* rh) as the input variables, selected the vent opening (u) as output variable. The corresponding fuzzy sets are *ΔT*, *ΔRH*, *U*.

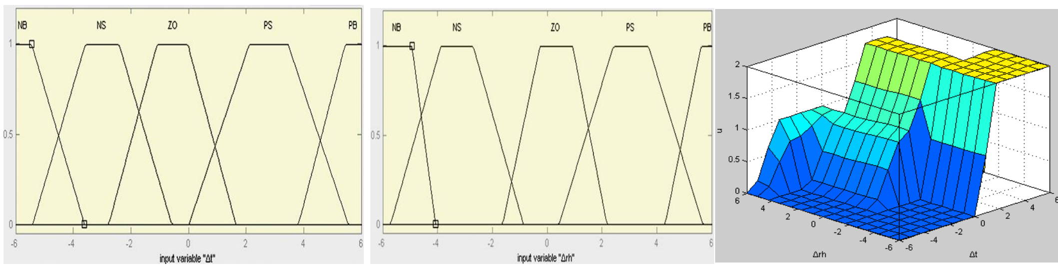
Chosen the 24 sample data, from 7:00 ~ 18:30, measured on April 20th, as the training data. According to the actual crop growth status, the indoor standard reference temperature and humidity were set to 24°C and 70% respectively. For convenience of fuzzification, the original range of *Δ* t and *Δ*rh were all quantized in the range of [6, 6], from [-10, 8.6] and [-29.5, 30] respectively.

This fuzzy system was initialized using the grid partition method, and 5 fuzzy subsets were set within the scope of the two input variables to describe 5 fuzzy states, they are NB (negative) and NS (negative), ZO (zero), PS (small) and PB (board). According to the requirements of the design, the sum algorithm selected the method "prod", and defuzzification selected the method "wtaver".

In network training process, the research adopted an adaptive neural network for training, whose optimization method was "backpropa", error precision was 0 (e=0) and the largest training number was 100 (Epochs=100). After 100 times of training, the error is close to 0 (the convergence error reached 0.00035243, it met the precision requirement, then network training finished.

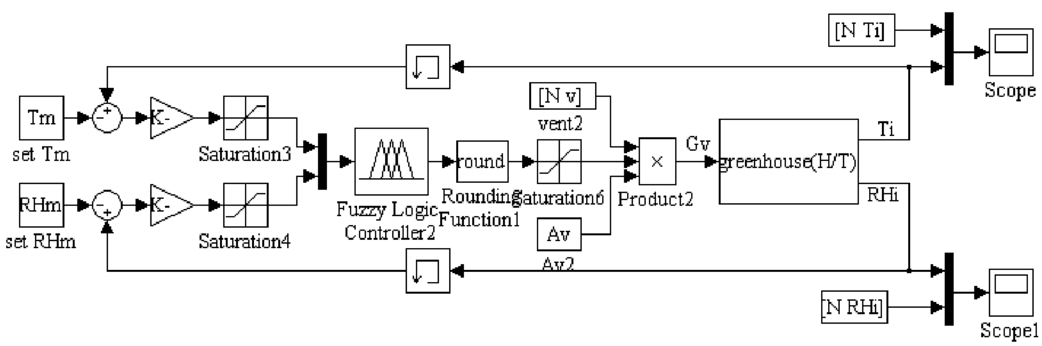
The input variables membership functions and controller three-dimensional structure are shown in Fig. 3.

Simulation diagram of control system: Combining greenhouse environment model with ventilation controller based on ANFIS, the graphical simulation diagram of greenhouse environment fuzzy control system is constructed by



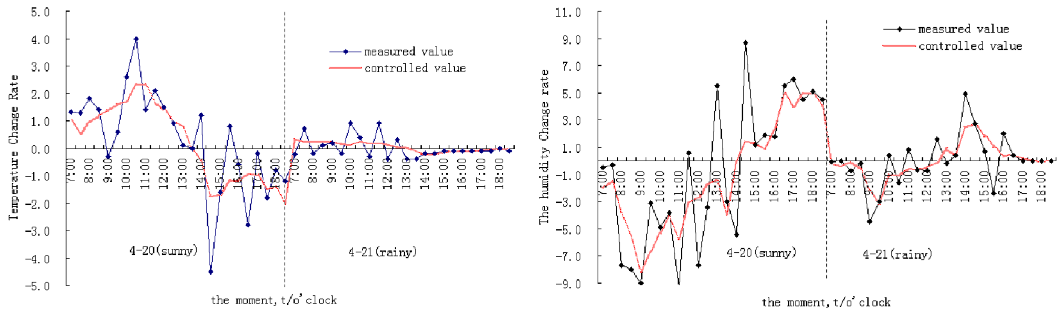
Note: NB-Negative Big; NS-Negative Small; ZO-Zero; PS-Positive Small; PB-Positive Big

Fig. 3: Membership functions of fuzzy controller.



Note: T_i,RH_i - controlled variables; G_v - greenhouse ventilation rate; *v*-the measured wind speed; *N* - sample size; the meaning of the other parameter as before.

Fig. 4: Greenhouse model with fuzzy control system.



(a) Temperature Change Rate (b) The Humidity Change Rate

Fig. 5: Contrast line between the measured data change rate and the fuzzy controlled one.

Simulink, as shown in Fig. 4.

RESULTS

As shown in Fig. 5(a), the indoor temperature gradient keeps between [-4.5, 4] in the artificial controlling ventilation condition, where the curve has 5 times through x-axis (thermostatic points) in sunny day, and 10 times in rainy day. However, by using the fuzzy control method, the range of indoor temperature gradient reduced to [-2.0, 2.3], there are only three times through x-axis in the consecutive two days, the curve fluctuation is relatively flat.

As shown in Fig. 5(b), the humidity gradient curve changes in the same rule. The indoor humidity gradient fluctuation ranges are [9.3, 8.7] and [8.2, 4.9], respectively in the condition of artificial control and fuzzy control, where the times through the x-axis by the curve in two days are respectively 13 and 3. It is obvious that fuzzy control system has optimally regulated the indoor temperature and humidity.

DISCUSSION

This paper completes the modeling process of greenhouse environment control system based on ANFIS, carries out simulation test on the model using the test data under two kinds of typical weather conditions, and proves that this control system not only can decrease the artificial error effectively, but also can reduce the interaction between control elements and disturbances outside. What is more, the control system reflects the validity and reliability of the neural fuzzy control in the processing of multi-input systems. All the feature of the control system has great help to the development of intelligent greenhouse. Although the experiment result is in view of the situation of greenhouse tomato in the E-Zhong area, it can provide some reference for other regions and crops.

However, the control methods of greenhouse are not limited to ventilation only but also include some other methods such as irrigation, laying sunshade net or cold protective quilt etc., which could be taken as focus in the future researches.

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