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Research on Multivariable Environmental Control Strategies in Confined Piggery

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ABSTRACT

To meet the demand for fine control of the environment of confined duct-ventilated nursery piggeries in winter in cold regions, the decoupling controller is designed based on the fuzzy control theory for graded control of environmental control and duct ventilation temperature compensation. The relative humidity deviation and carbon dioxide concentration deviation are used as the input variables, the fan speed control mode is the output amount, and the enclosure is a ventilation unit for local control. The control variables are fuzzified and defuzzified, establishing fuzzy control rules to realize the control of variable speed and variable ventilation. At the same time, in order to ensure that the air supply temperature is suitable, the duct ventilation air is preheated to realize the hierarchical control of duct ventilation and heating compensation. The regulatory system pig barn environment is simulated using Matlab / Simulink to verify the feasibility of ventilation variables and variable speed control. The simulation results show that the air supply temperature after ventilation and preheating is within the suitable growth range of nursery pigs, and all environmental parameters of the nursery piggeries meet the Chinese national standard. Multivariate environmental control provides technical support for the practical application of duct ventilation and lays a foundation for the automatic control of the environment in the piggeries.

1. Introduction

In the process of pig breeding, ventilation is the best way to ensure the air quality in the confined piggery. In cold winter, if only insulation is considered, harmful gases such as NH_3, H_2S, and CO_2 in the piggery, as well as excessive water vapor and dust, seriously affect the healthy growth of pigs, and also cause great harm to the health of the feeding personnel (Zhou D et al.2018; Li H et al. 2019; Cao MB et al. 2020). To meet the needs of healthy pig breeding, it is crucial to alleviate the contradiction between the ventilation and insulation of confined piggery.

The establishment of a comprehensive environmental control system of environmental monitoring, automatic control, and output treatment can effectively improve the efficiency of breeding work and ensure the air quality in the piggery (Rong N et al.2022). By adjusting the ventilation variable, combining the location, feeding period, and the growth state of pigs can keep the environment within the suitable growth range of pigs and minimize the heat loss of ventilation. They designed a double fuzzy adaptive PID control system to control the temperature and humidity in the piggery. The temperature and humidity are more appropriate, and the fluctuation range is small (Zhang MW et al. 2021). The method combined the prediction results of the GRU model and fuzzy control algorithm to control the temperature and humidity in the piggery. The method reduced the abnormal temperature in the piggery by about 90%, and the control effect is good (Jin H et al.2022). They designed fuzzy decoupling control strategies and established an environmental control model according to the characteristics of environmental changes in different seasons in winter and summer. The test results showed that the effect of adopting a multi-environmental factor control strategy is more satisfying to the needs of fine control of healthy pig breeding than single variable control (Xie QJ et al. 2017). By studying the temperature and humidity control of sow house based on the adaptive fuzzy PID to control algorithm. The measured results showed that the control deviation was reduced and the accuracy of temperature and humidity control was guaranteed (Feng J et al.2018). Wu et al. (2016) used fuzzy control technology to achieve effective control of temperature and humidity in the greenhouse environment by addressing the characteristics of nonlinearity, temporality, delay, and multivariate coupling. The simulation results showed that the system has a fast response speed and strong anti-interference ability. The above research showed that fuzzy control, as an intelligent control method, can effectively carry out environmental control and be applied to the environmental control system of livestock and

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poultry piggeries, to provide technical support for automatic and intelligent breeding (Wu ZD et al. 2021; Xie QJ et al. 2023; Huang JS et al. 2021)

According to the environmental characteristics of the piggery, this paper adopts multivariable fuzzy decoupling and control to study the ventilation and ventilation control system of the air supply and exhaust duct, optimize the environmental control system of the piggery, and explore the methods that are easy to meet the real-time control requirements of the small environment.

2. Details Experimental

2.1 Materials and Procedures

The environmental control data of this piggery comes from a nursery piggery (Wu ZD et al.2021) in Qiqihar City, Heilongjiang Province. There are two Windows on the south side of the piggery, and two Windows and one door on the north side of the side of the corridor. The area of a single nursery pen is 170 m^2. There are 12 pens in each nursery. Each pen is 3.5 m long and 2.5 m wide. Fig. 1 shows the photo of the experimental nursery pen. The nursery piggery adopts the combined ventilation system of air supply and exhaust duct, with the fence as the unit. The fresh air outside the piggery is heated to meet the growth needs of the nursery pigs and enters the piggery through the air supply duct. The dirty gas and water vapor in the piggery are sent out of the piggery through the exhaust duct.

Fig.1. Experimental conservation nursery piggery.

Using an environmental monitoring system based on LoRa, pump suction gas detector (model: HD5S +, precision: 0.1mg/m^3, error: ± 3%FS) and temperature and humidity sensor module (SHT 30, temperature accuracy: 0.01 °C, humidity accuracy: 0.01 % RH, error: ± 0.2 °C) are monitored. Compared with the national standard, the temperature in the piggery is always within the appropriate range. Due to the timely waste treatment of feces, the harmful gases such as NH_3 and H_2S are less, the concentration of harmful gases meets the standard requirements, and the CO_2 and humidity seriously exceed the standard.

2.2. Environmental control system design

2.2.1. Overall design of the system

The composition of the regulatory system is shown in Fig. 2, including the environmental data acquisition module, control terminal, and upper computer. The environmental data acquisition module collects the environmental data of the temperature, humidity, CO_2 and NH_3 concentration in the piggery. The data is transmitted to the control terminal through LoRa wireless communication. The control terminal microcontroller processes the data. The fuzzy control algorithm is adopted to control the environmental control equipment in real time through the drive module, including the fan and the heating compensator. By controlling the heating compensator, the ventilation is pretreated to ensure that the temperature in the piggery is not affected by ventilation. The ventilation system is crucial to the environmental control of the piggery. By controlling the operation of the fan to adjust the ventilation capacity, it can effectively eliminate harmful gases, reduce the temperature and humidity, and provide a good growth environment for pigs. The staff can set relevant parameters and observe the environment changes through the upper computer. It can extend the GPRS wireless communication module to communicate wirelessly with the host computer according to the demand, and realise the extended function of remote monitoring.

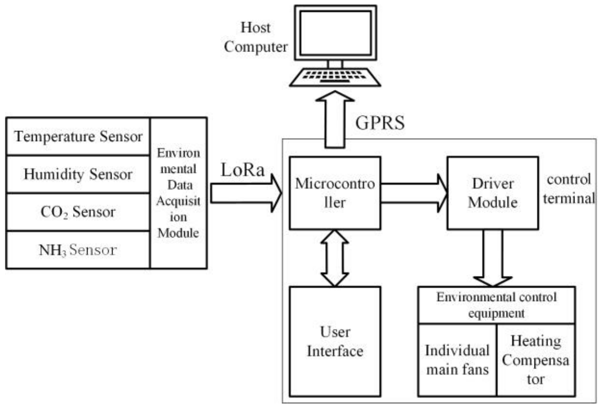


Fig. 2. Regulatory system composition.

2.2.2. Fuzzy control of the piggery environment

The environment of the piggery is characterized by nonlinear, time-varying, large lag, and strong coupling, which can not meet the requirements of establishing an accurate numerical model of the environment in the piggery. The traditional control can not achieve the accurate dynamic control effect (Keshtkar A et al.2017; Hao LM et al. 2021). Fuzzy control is a nonlinear control, which makes it difficult to accurately describe variables, and the fuzzy control method is more suitable for multivariable environmental control in piggery. The structure of the piggery fuzzy control system is shown in Fig. 3.

To ensure the efficient and stable operation of the system, effectively reduce the oscillation phenomenon of the system response process, and prevent the nursery pigs from experiencing cold stress. The environmental control system of piggery is designed. It includes two parts: ventilation system fuzzy control and temperature compensation fuzzy control. In winter, the temperature outside the piggery in cold areas is low, and the temperature in the piggery decreases significantly during ventilation. To eliminate the influence of ventilation on the temperature in the piggery, the ventilation is pretreated by corridor preheating, heat exchange, and ventilation heating, which can ensure that the air supply temperature is suitable for the growth of nursery pigs. In the case that the air supply temperature is appropriate. The ventilation fuzzy control takes the difference between the relative humidity monitoring value and the preset value ΔS and the CO_2 concentration monitoring value and the preset value ΔE as the control input variable, and the fan speed control mode Y_f is taken as the output variable.

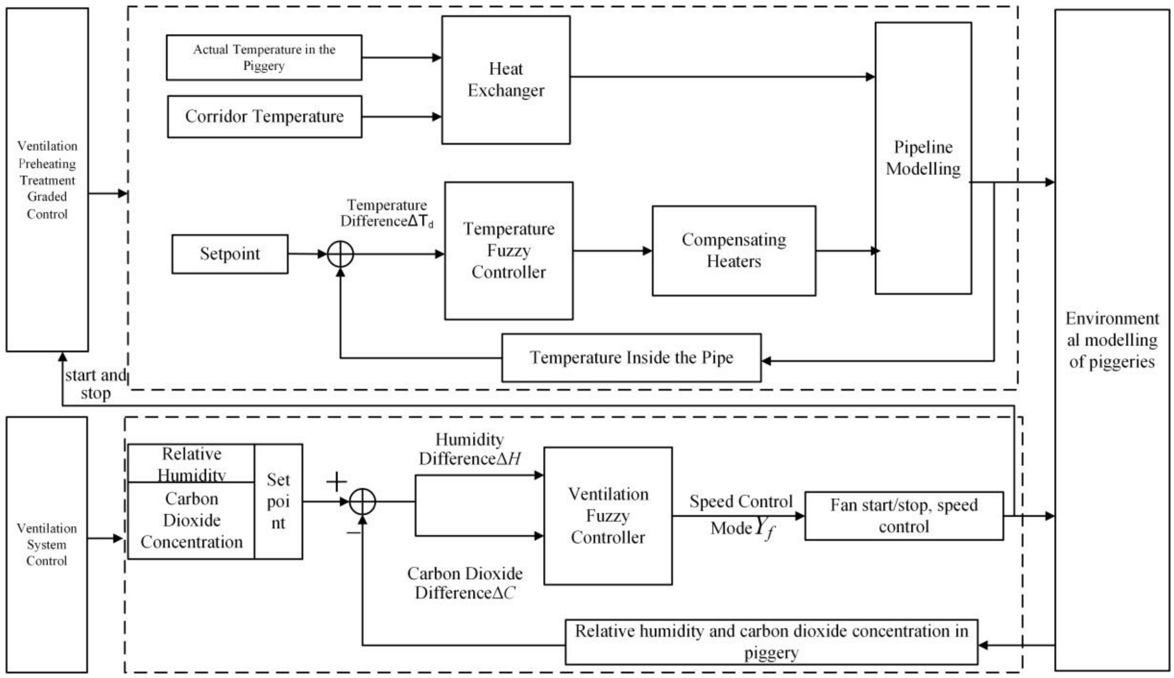


Fig. 3. Structure of the environmental control system.

2.3. Design of environmental fuzzy controller

2.3.1. Fuzzy control of the ventilation system

The fuzzy input variables are the difference between the relative humidity monitoring value and the preset value △S, and the difference between the carbon dioxide concentration monitoring value and the preset value △E. As can be seen from GB/T 17824.3-2008 "Environmental Parameters and Environmental Management of Large-Scale Pig Farms", the appropriate range of relative humidity in the piggery is 60-70 percent, with 65 percent as the optimum preset value for humidity; the concentration of carbon dioxide should not exceed 1,300 mg/cm^3, and the relative humidity in the house should be 60-70 percent. 600 mg/m^3 was the preset value for carbon dioxide concentration. The relative humidity deviation ΔH fundamental domain $e \in$ {-6 %, + 6 %}, the verbal domain is {-3, -2, -1,0,1,2,3}. The carbon dioxide deviation ΔS fundamental domain $e \in$ {-600, + 600}, the verbal domain is {-300, -200, - -100,0,100,200,300} to simplify the calculation. The fuzzy sets ΔS and ΔE fuzzy sets of relative humidity deviation ΔS and ammonia concentration deviation ΔE are defined as {Big negative, negative medium, small negative, zero, positive small, medium, square}. To facilitate system follow-up and simulation, the fuzzy set can be expressed as {NB, NM, NS, Z, PS, PM, PB}. Input variable quanfier K_S=0.5 and K_E=0.5. The triangle membership function is selected. The relative humidity deviation ΔS and the carbon dioxide concentration deviation ΔE membership function are shown in Tab.1.

Tab. 1. Relative humidity deviation and e_H membership values.

S/E	-3	-2	-1	0	1	2	3
NB	0	0	0	0	0	0	0
NM	0	1	0	0	0	0	0
NS	0	0	1	0	0	0	0
Z	0	0	0	1	0	0	0
PS	0	0	0	0	1	0	0
PM	0	0	0	0	0	1	0
PB	0	0	0	0	0	0	1

Depending on the number λ of air supply fans activated in each enclosure, it controls the deflector fan with thermal compensator at variable speed. The speed control mode of the fan Y_f includes: shutdown (λ =0), low speed (0 <λ< 2), medium speed (2 <λ< 4), and high speed (4 <λ< 6), and domain is [0,1,2,3]. The fuzzy set is [shutdown, low speed, medium speed, high speed], namely [Z, PS, PM, PB], and the output quantification factor K_y = 1. The fuzzy rule control table is established as shown in Tab.2.

Tab. 2. Fuzzy control rule.

ΔS / Y_f / ΔE	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	Z	Z	Z	PS	PM
NM	Z	Z	Z	Z	Z	PS	PM
NS	Z	Z	Z	Z	PS	PM	PM
Z	Z	PS	PS	PS	PM	PM	PB
PS	Z	PS	PS	PM	PB	PB	PB
PM	PS	PS	PM	PM	PB	PB	PB
PB	PS	PS	PM	PM	PB	PB	PB

2.3.2. Temperature compensation and fuzzy control

In winter, the temperature difference inside and outside the piggery is large. To reduce heat loss and ventilation energy consumption, the fuzzy control method is adopted to realize the hierarchical control of duct ventilation and heating compensation. The fuzzy control of temperature compensation is linked with the stop and start of the fan. When the fan starts, the temperature compensation system starts to work. In winter, the outdoor temperature is -14~ -25°C.

Tab. 3. Resistance power.

Resistor number	Capacity	Compensation temperature
1	0.68	1
2	1.36	2
3	1.36	2
4	2.04	3

The entrance of adding fuel to the warming bed is set on the side of the corridor to preheat the outdoor air entering the corridor so that the temperature in the corridor reaches between 4 and 8°C. After preheating the corridor, the fresh air heats the old wind through the heat exchanger at the same time. The heat exchange efficiency of the heat exchanger is 70 percent, and the temperature can be increased to more than 12~15°C. To make the temperature in the nursery piggery not affected by ventilation, the temperature of the fresh air inlet must reach the appropriate range of the nursery piggery, and the fresh air after heat exchange to compensate for the heat, and the compensation temperature is 5~8 °C. After ventilation and preheating treatment, the fresh air inlet temperature reaches about 20 °C. The compensation heater is heated by 4 resistors in parallel, and the power of each resistance is shown in Tab. 3. The fuzzy control method is used to classify the compensation heater, and the resistance is controlled by combination, and the hierarchical combination form is shown in Tab.4. Any temperature compensation in the range of 1~8°C can be achieved.

Tab. 4. Hierarchical combination table.

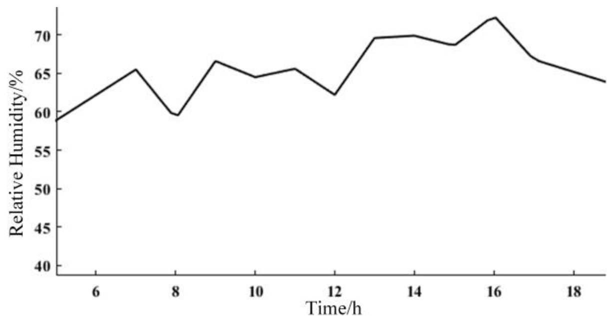
Compound mode	Compound mode 1	Compound mode 2	Compound mode 3	Compound mode 4
1	N	F	F	F
2	F	N	F	F
3	N	F	N	F
4	F	N	N	F
5	F	N	F	N
6	N	N	F	N
7	F	N	N	N
8	N	N	N	N

Note: N is open and F is closed.

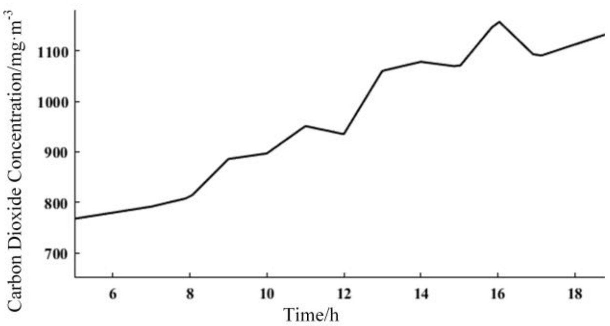
3. Results and analysis

To verify whether the fuzzy control of the ventilation system can realize the variable ventilation function, the environmental monitoring data of the experimental piggery from 6:00 to 18:00 on January 19 are simulated as the input value. The data of relative humidity and carbon dioxide concentration of ventilation control are shown in Fig.4. The relative humidity and carbon dioxide concentration are both in line with the national standards, which are suitable for the healthy growth of nursery pigs, and the control system meets the environmental control needs of nursery pigs.

After the field test, the temperature of the corridor was monitored by a thermometer at 4~8 ℃. For the environmental data of each area in the piggery, the environmental parameters were within the healthy growth range of the nursery pigs. The temperature of the piggery was 20~25 ℃, the relative humidity was less than 75percent, the NH_3 concentration was less than 5 mg/m^3, and the CO_2 concentration was less than 1200 mg / m^3. This paper designs the control system to meet the needs of fine control of piggery. The temperature of the environmental controller of the piggery is set at 20℃, the relative humidity in the piggery is set at 65percent, and the carbon dioxide concentration is set at 600 mg / m^3, and the environmental data of the piggery collected on January 5 is used to verify the environmental control system. Environmental control model using MATLAB / Simulink software tools, the fresh air inlet temperature curve is shown in Fig. 5.



a. Relative humidity.



b. Carbon dioxide concentration.

Fig.4. Simulation curve of relative humidity and carbon dioxide concentration.

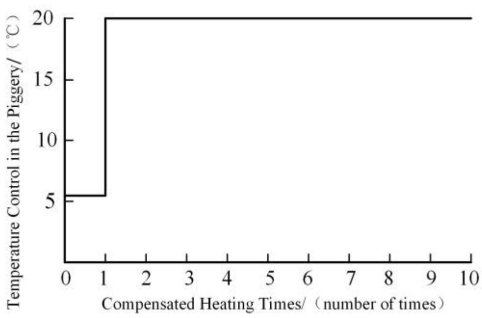


Fig .5. Simulation curve of fresh air inlet temperature.

The initial temperature is 5.2 ℃, which is the temperature of the connecting corridor. After opening the heat exchanger and the heating compensator, the temperature is kept within the allowable error range of the set value, and the grading control is effective.

4. Conclusion

According to environmental measurement data and fuzzy control theory, the main conclusions are summarized as follows:

1. According to the starting number of each fence ventilation fan, the variable speed of the fan is controlled. The carbon dioxide concentration and relative humidity are taken as the control input of the ventilation control system, and the fan speed control mode is taken as the output, including four modes: shutdown, low speed, medium speed, and high speed. The ventilation control system model of the experimental piggery is constructed by MATLAB / Simulink. The measured relative humidity and carbon dioxide concentration data of the experimental piggery are the input value, and the switching function can be realized step by step. After the field test, the environmental parameters of the test piggery are in line with the Chinese national standard, which can be variable speed and variable ventilation control to reduce energy consumption.

2. The fuzzy control method is adopted to preheat the ventilation, the air temperature is preheated to 5.2℃, the heat temperature is increased to 12~15℃ through the heat exchanger, and the ventilation preconditioning control model is established through MATLAB / Simulink. The results show that the fresh air inlet temperature is about 20℃, within the allowable error range of the setting value to meet the healthy growth requirements of nursery pigs.

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