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การควบคุมสภาพอากาศภายในโรงเรือนเลี้ยงไก่ระบบปิดโดยใช้ตัวควบคุมฟัซซี่ลอจิก

Poultry house climate control using a Fuzzy Logic Controller

ณัฐสุพร ชิ้นสุวรรณ[1], กฤษณรัช นิติสิริ[2], นิยม พินิจการ[3], ธนา ราษฎร์ภักดี[2*] และ ชนกนันท์ สุขกำเนิด[4]

Nutsuporn Chinsuwan[1], Krisanarach Nitisiri[2], Niyom Pinitkarn[3], Thana Radpukdee[2] and Chanoknun Sookkumnerd[4]

[1]ภาควิชาวิศวกรรมวัสดุและการผลิต, คณะวิศวกรรมศาสตร์, มหาวิทยาลัยขอนแก่น

[2]ภาควิชาวิศวกรรมอุตสาหการ, คณะวิศวกรรมศาสตร์, มหาวิทยาลัยขอนแก่น

[3]ภาควิชาวิศวกรรมไฟฟ้า, คณะวิศวกรรมศาสตร์, มหาวิทยาลัยขอนแก่น

[4]ภาควิชาวิศวกรรมเครื่องกล, คณะวิศวกรรมศาสตร์, มหาวิทยาลัยขอนแก่น

[1]Department of Materials and Manufacturing Engineering, Faculty of Engineering, Khon Kaen University

[2]Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University

[3]Department of Electrical Engineering, Faculty of Engineering, Khon Kaen University

[4]Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University

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บทคัดย่อ

บทความนี้พัฒนาตัวควบคุมแบบฟัซซี่ลอจิกในการควบคุมระบบทำความเย็นแบบระเหยสำหรับควบคุมสภาพอากาศในโรงเรือนเลี้ยงสัตว์ปีก ตัวควบคุมแบบฟัซซี่ลอจิกมีประสิทธิภาพดี และง่ายต่อการนำไปใช้กับระบบที่ซับซ้อน การควบคุมสภาพอากาศในโรงเรือนเลี้ยงสัตว์ปีกเป็นระบบไม่เป็นเชิงเส้น ซับซ้อน และยากต่อการควบคุม ดังนั้น เราจึงใช้ตัวควบคุมแบบฟัซซี่ลอจิกเพื่อควบคุมอุณหภูมิภายในและความชื้นสัมพัทธ์แบบป้อนกลับ งานวิจัยนี้ได้ออกแบบตัวควบคุมแบบฟัซซี่ลอจิก 2 ตัว สำหรับควบคุมพัดลม และปั๊มน้ำ ในการออกแบบตัวควบคุมทั้งสองใช้อินพุต 4 ตัวและเอาต์พุต 1 ตัว โดยมีค่าคลาดเคลื่อนและการเปลี่ยนแปลง

ค่าคลาดเคลื่อนของค่าอุณหภูมิ และความชื้นสัมพัทธ์เป็นอินพุตของระบบ ถูกเปลี่ยนให้กลายเป็นตัวแปรทางภาษาด้วย membership function และใช้กฎ IF-THEN ที่สร้างจากความเข้าใจเรื่องเฟสระนาบ เพื่อหาค่าเอาต์พุตของระบบ ได้แก่ อัตราการเปลี่ยนแปลงของการระบายอากาศ และอัตราการสร้างความชื้น ในบทความนี้ สมรรถนะของตัวควบคุมที่นำเสนอจะเปรียบเทียบด้วยค่าความคลาดเคลื่อนเฉลี่ย และค่าความคลาดเคลื่อนกับตัวควบคุมแบบดั้งเดิม ผลทดสอบพบว่าตัวควบคุมที่นำเสนอ สามารถควบคุมอุณหภูมิ และความชื้นสัมพัทธ์ให้คงที่ในช่วงให้คงที่อยู่ในช่วง ± 1.5 °C และ ± 20% ตามลำดับได้ซึ่งดีกว่าตัวควบคุมแบบเดิม สำหรับงานวิจัยถัดไปผู้วิจัยจะพัฒนา membership function ให้มีความละเอียดสูงขึ้นเพื่อปรับปรุงผลตอบสนองให้ดียิ่งขึ้น
คำสำคัญ: ระบบปรับอากาศ ฟาร์มไก่ การควบคุมอุณหภูมิ การควบคุมความชื้น ระบบควบคุมอัตโนมัติ

Abstract

The aim of this paper is developing a Fuzzy Logic Controller (FLC) to control climate with evaporative cooling system in model of poultyr house. In recent year, many studys show that FLC has good performance and simple to apply with a complex system and poultry house climate control is nonlinear system which is complex and difficult to control. Thus we apply FLC to control this system. By internal temperature and relative humidity, important index indicating thermal comfort, is feedback signal.
In the design, 2 FLCs used for controlling fans and pump. Both FLCs use the structure of 4 inputs and 1 output. The error and the error derivative of temperature and relative humidity are the input of the system. These are translated to linguistic valuables by the membership function and through fuzzy processes according to If-Then rule which based on phase plane analysis to arrive at single value, and then defuzzification to get value of the change of ventilation rate and moisture production rate.
The maximum and average error is collected to propose FLC comparing with a conventional control system. The result shows that FLC can control temperature in ± 1.5 °C range and relative humidity control in ± 20% range. The FLC has better performance than a conventional system. For the future work , to improve relative humidity response the finer membership function should be apply.
Keyword: Evaporative cooling system: Chicken house: Pad-fan cooling: Automatic control system

*ติดต่อ: E-mail tthanar@gmail.com, เบอร์โทรสาร 043-347-227

1. Introduction

In Thailand, the demand for chicken is expected to increase, so suppliers try to improve themselves for competitiveness. Animal welfare is potential for increased productivity and profit in the farm sector [1]. Poultry needs a suitable environment. The heat stress stimulates the central nervous system (CNS), which reduces feed intake, weight gain and carcass quality of poultry [2]. Temperature and relative humidity are essential factors that have to maintain at a comfortable level. Because of hot and dry weather in Thailand, poultry meat production uses an evaporative cooling system for controlling inside climate. The difficulty of controlling is uncertainty from disturbance that is the changing of the external climate. Providing a method for accuracy controlling is essential for animal husbandry.

Fuzzy logic was first introduced by Lotfi A. Zadeh (1973), he proposed the fundamental of fuzzy sets [3-4]. And then Ebrahim Mamdani (1975) introduced the fuzzy interface system to control a stream engine [5]. It involves fuzzification and defuzzification of crisp input variables to derive crisp output variables. Fuzzy interface system had widespread acceptance. Fuzzy control is a popular control technique because of its performance and simplicity. It is much closer to human thinking and natural language [6]. It converts the linguistic control strategy based on human-like decision making in to an automatic control strategy. Fuzzy Logic Controller (FLC) consists of three stages fuzzification, rules base and defuzzification based on Mamdani fuzzy set [6]. In closed loop control system, the system error and change of error are input variables. FLC assigns these crisp variables in to linguistic variables which are national language words defined by Membership Functions (MFs) [7]. This conversion is fuzzification. And the next stage is the fuzzy rule base which is relation between input and output variable in form of IF-Then. There are many techniques for constructing a fuzzy rule base with the heuristic method [8]. The common technique is the Phase-Plane Trajectory method. King and Mamdani (1977) introduce a useful method for control rule by referring to a closed system trajectory in a phase plane [9]. In last stage, defuzzification, fuzzy outputs are converted to crisp value as control signals. During the past several years, there are many related works of a FLC design for controlling temperature or humidity in building and agricultural usage [10-12]. They concluded that FLC has better control quality occurred.

This study develops the FLC to control evaporative cooling system. The poultry house model in Lopburi province, Central of Thailand from previous work [13] is provided for simulation. The conventional control method is week by week schedule for fans and pumps. We intend to find a simple and optimum method to manage the operation time of actuators for better controlling temperature and relative humidity than the conventional control which is current used in actual plant. In this study, the fuzzy logic method is applied to get higher accuracy.

2. Materials and Methods

2.1 System definition

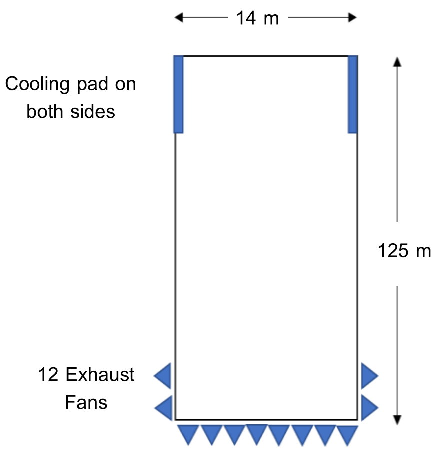

Fig. 1 Elements of the poultry house

Elements of the poultry house are shown in Fig 1. Pad-fan evaporative cooling system is used for controlling the climate in the poultry house. Poultry house case study is in Lopburi, Central of Thailand. A mathematical model of the actual plant for this study is obtained from Uachaba T. et. al., 2016 [13].

In this study, internal temperature (T_{int} in °C) and humidity ratio (ω_{int} in $kg_{H_2O}/kg_{Dry\ air}$) represent the internal climate condition. Dynamics model of the poultry house is described with heat and mass balance equations by:

$$\frac{dT_{int}(t)}{dt} = \frac{N_{an}\times 0.013\times[0.8 - 1.85\times 10^{-7}(T_{int}+10)^4]}{\rho_{air}C_pV_T} + \frac{UA(T_{ext} - T_{int}) - \lambda W_{ev}}{\rho_{air}C_pV_T} - \frac{V_R(T_{ext} - T_{int})}{V_T} \quad (1)$$

$$\frac{d\omega_{int}(t)}{dt} = \frac{N_{an}\times 0.001\times[0.26T_{int}^2 - 6.465T_{int} + 81.6] + W_{ev}}{\rho_{air}V_H} - \frac{V_R(\omega_{ext} - \omega_{int})}{V_H} \quad (2)$$

where T_{ext} is external temperature [°C]

ω_{ext} is external humidity ratio

N_{an} is the number of animals

UA is overall heat transfer coefficient [kW/K]

λ is heat vaporization of water [kJ/kg]

ρ_{air} is air density [kg/m^3]

C_p is the specific heat of air [kJ/kg·K]

V_T is active mixing volume of air inside [m^3]

V_H is the effective volume for humidity [m^3]

V_R is ventilation rate [m^3/s]

W_{ev} is moisture production rate from the evaporative cooling system [kg/s]

V_R and W_{ev} are control signals from fans and pump, respectively.

As these actuators operate without an inverter, signals aren't analogue. The next section is focused on a control technique that handles the nonlinear system with on/off actuator by FLC

2.2 Design of fuzzy logic controller

FLC is a means to convert the linguistic control strategy form human expert knowledge into an automatic control strategy. Its advantage is simplicity, especially when the implemented system is very complicated. It is accessible for dealing with a highly complicated nonlinear system. The methodology of FLC consists of three processes, fuzzification, rules-based and defuzzification [6].

The simulink model of controlling the poultry house is shown in Fig. 2. There are two FLCs used for controlling fans and pump. Both FLCs have 4 inputs and 1 output. The inputs variables are temperature error (TE), temperature error derivative (TDE), relative humidity error (HE) and relative humidity error derivative (HDE). These inputs variables are transformed into three linguistic variables, N : Negative , Z : Zero and P: Positive. These linguistic variables represent the type of number: negative number, zero number and positive number. The outputs are the change of ventilation rate (DVR in m^3/s^2) and moisture production rate (DWev in kg/s^2) for first and second FLC, respectively. These output variables are transformed into three linguistic variables, same as the input variables. The triangular membership functions of input and output variables of FLCs are shown in Fig. 3.

A total of 36 rules is tabulated in Table 1-4. The first and second FLC rules are tabulated in Table 1-2 and 3-4, respectively. These rules are built for the most essential variable temperature followed by relative humidity. Thus the weight of temperature rules (Table 1,3), 1, is more than the weight of relative humidity rules (Table 2,4), 0.1. Considering the equation (1) and (2) conclude that increasing the ventilation rate generated by the fans decreases the temperature and relative humidity. Increasing moisture production rate generated by the pump, providing water for the cooling pad, will reduce temperature but increase relative humidity. This knowledge is used to build FLC rules with a understanding of parameter-adjusting based on phase plane [6].

The rule base of Table 1 can be described in IF-THEN form as:

Control rules when the error is negative, so DVR is positive:

IF {TE is N AND TDE is N} THEN DVR is P

IF {TE is N AND TDE is Z} THEN DVR is P

IF {TE is N AND TDE is P} THEN DVR is P

Control rule at equilibrium point, so DVR is unchanged.

IF {TE is Z AND TDE is Z} THEN DVR is Z

Control rules when the error is positive, so DVR is negative:

IF {TE is P AND TDE is P} THEN DVR is N

IF {TE is P AND TDE is N} THEN DVR is N

IF {TE is P AND TDE is Z} THEN DVR is N

Control rule when the error is zero, so DVR is opposite to TDE for reduce the overshoot.

IF {TE is Z AND TDE is P} THEN DVR is N

IF {TE is Z AND TDE is N} THEN DVR is P

The FLC rules in Table 2-4 is built in the same way as Table 1, but be changed follow the relation of input and output variables.

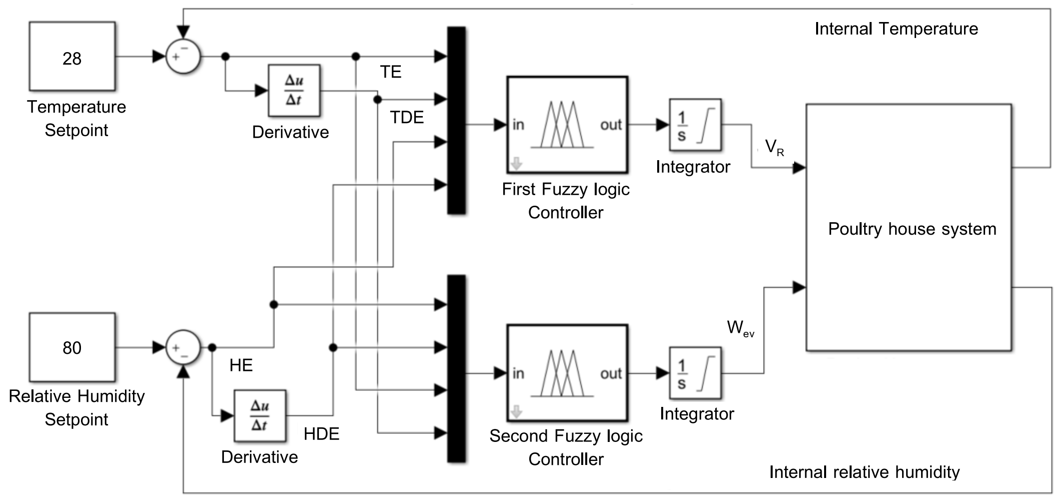

Fig. 2 Simulink model for controlling the climate of poultry house

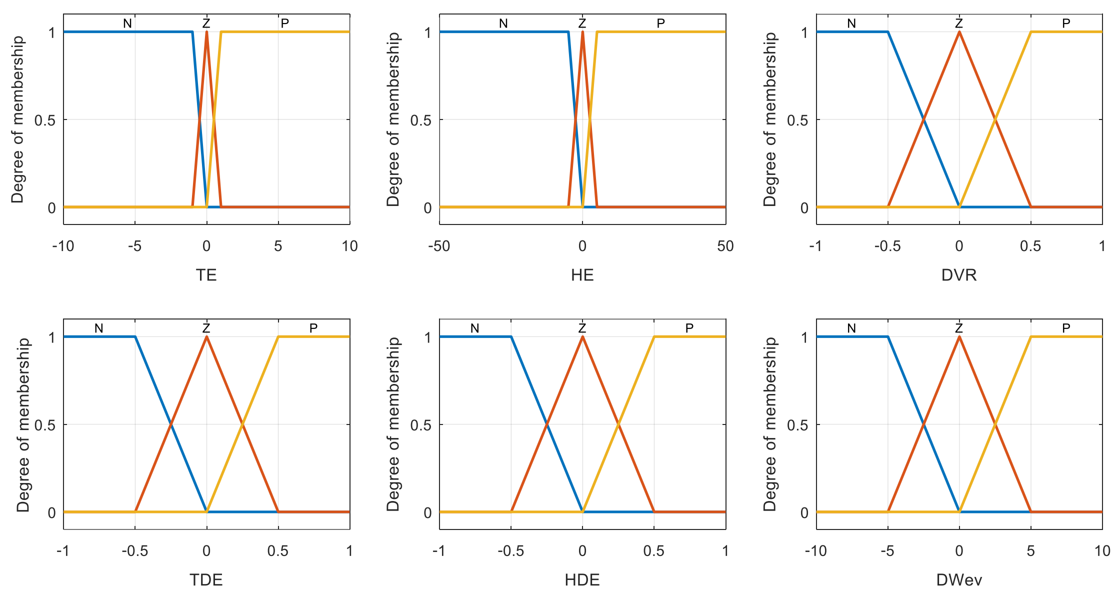

Fig. 3 The membership functions of input and output variables of FLCs

The simulation for climate controlling in the poultry house uses 3-days historical weather data from the chicken house from 16th to 18th August 2019. The parameters of equation 1 and 2 are listed in Table 6. The simulation compares temperature and relative humidity responses between the proposed FLC and the conventional control logic, which is currently used in the plant. Conventional control logic plan for controlling fans and pump are shown in Table 5. The control table is for 8-10 days-age chicken. On/off period for fans and pump are 90/120 s/s and 60/420 s/s, respectively.

Table 1 The fuzzy temperature rules of the first FLC

DVR		TE N	TE Z	TE P
TDE	N	P	P	N
	Z	P	Z	N
	P	P	N	N

Table 2 The fuzzy humidity rules of the first FLC

DVR		HE N	HE Z	HE P
HDE	N	P	P	N
	Z	P	Z	N
	P	P	N	N

Table 3 The fuzzy temperature rules of the second FLC

Dwev		TE N	TE Z	TE P
TDE	N	P	P	N
	Z	P	Z	N
	P	P	N	N

Table 4 The fuzzy humidity rules of the second FLC

Dwev		HE N	HE Z	HE P
HDE	N	N	N	P
	Z	N	Z	P
	P	N	P	P

Table 5 Conventional control logic for actuators

Internal Temperature (℃)	Number of Fans	Pump status
<28	4	off
28	5	off
29	6	on
30	7	on
31	9	on
32	12	on

Table 6 Parameter values of the case study

Parameter	Value
N_{an}	19000
λ	2257 kJ/Kg
V_T	4900 m^3
V_H	4900 m^3
ρ_{air}	1.2 kg/m^3
C_p	1.006 kJ/kg·K
U	37 $kW/K{\cdot}m^2$
A	1680 m^2
W_{ev}	0.9 kg/s for turn on pump
V_R	5.66 m^3 /s·fan (max 12 fans)

3. Result and discussion

The comparison of temperature and relative humidity responses for the FLC and the conventional control logic is shown in Fig. 4 and 5. From these Figs, outdoor temperature varied from 26 to 37 °C and outdoor relative humidity varied from 45 to 90% with changing outdoor condition FLC maintains temperature and relative humidity in less than ± 1.24 °C and ± 20% from the set point 28 °C and 80%.

Table 7 Comparison of average and maximum error

Method	Avg. error	Max. error
Temperature (°C)		
Proposed FLC	0.54	1.24
Conventional system	1.12	2.40
Relative humidity (%)		
Proposed FLC	15.44	20
Conventional system	17.76	20

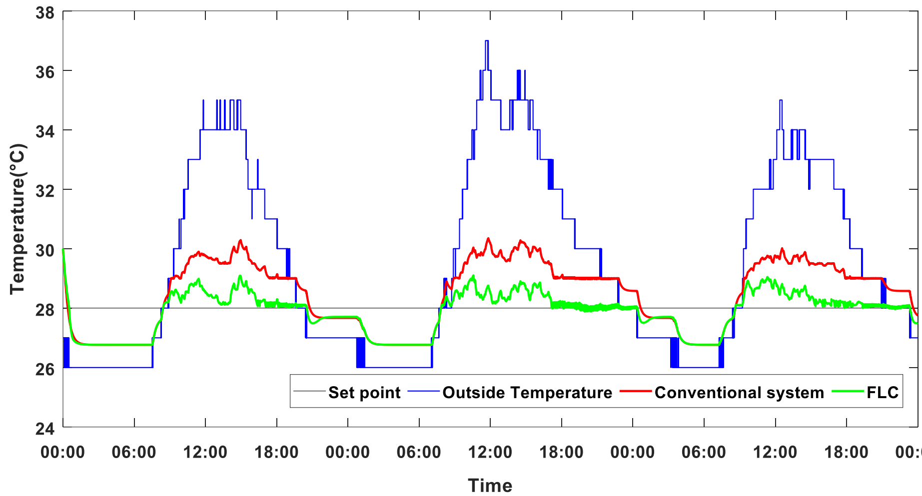

Fig. 4 Temperature curve from setpoint, outside, inside by conventional system and Fuzzy logic controller

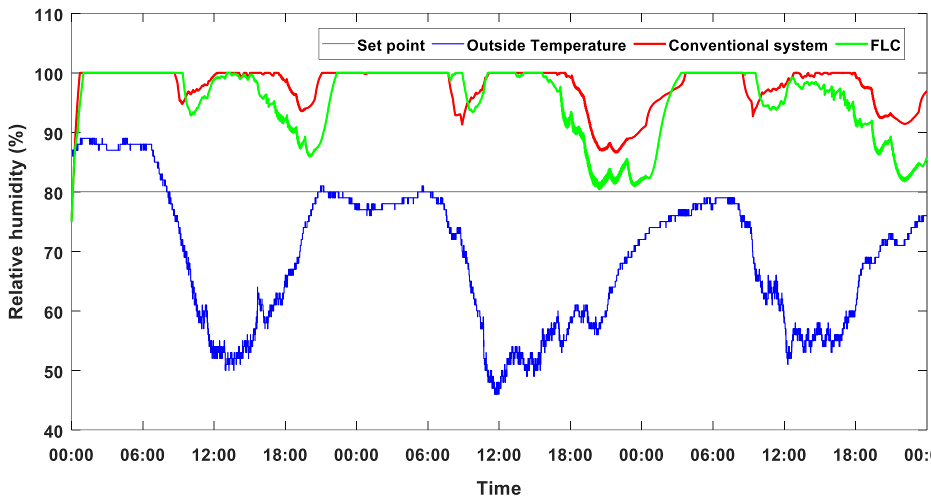

Fig. 5 Relative humidity curve from setpoint, outside, inside by conventional system and Fuzzy logic controller

According to Table 7 FLC has less average error and maximum error in temperature response, while take more 1% average error than the conventional system in relative humidity response. The result indicates that the FLC provides better temperature response, lower error and better performance against disturbance. A similar result for research on the comparison of fuzzy and on/off controllers for winter season indoor climate management in a model poultry house by Mirzaee-Ghaleh, et al [12] that the fuzzy logic controller has good performance.

The relative humidity response from both control techniques reach a high level (100%) because of poultry and surrounding. This result is consistent with the research of Kamis, et al. [10]

on closed-house chicken ban climate control using a fuzzy inference system that provides slightly high steady state error for relative humidity. We can conclude that this system lacks of controlling internal humidity with the accuracy temperature. In a further study, the finer membership function of FLC may be proposed to improve RH response.

4. Conclusion

The thermal comfort is a potential factor for increase poultry weight gain and carcass quality because heat stress reduces feed consumption and increases the risk of disease and death. For high productivity, suppliers have to control the internal climate of the poultry house. This study simulated controlling internal temperature and relative humidity of a poultry house by Fuzzy logic controller compared with the conventional logic control. The chicken house in the central of Thailand, Lopburi province modeled by Uachaba et al. [13] was provided for simulation experiments. The results shown that the proposed fuzzy logic controller can control internal temperature higher accuracy than the conventional control under the changing of outdoor conditions. The accuracy response of relative humidity may be improved by a finer membership function.

5. Acknowledgement

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