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STUDY ON APPLICATION OF FUZZY CONTROL IN AGRICULTURAL GREENHOUSE

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With the development of agricultural technology, greenhouse-grown vegetables and fruits appear in the public's field of vision. To adjust the parameters that affect the growth of greenhouse crops, and then improve the planting area and fruit yield. This paper considers that the temperature and humidity in the greenhouse planting environment has the characteristics of non-uniformity, variability and delay, through the comparison of fuzzy control, PID control and fuzzy PID control, the influence of different control methods to eliminate environmental factors was analyzed. Through the study of greenhouse environment system and Cherry Growth Environment Index, the system scheme of greenhouse control was determined. At the same time, taking cherry as an example, the expert decision-making of Cherry Greenhouse Control System is put forward, which provides a reference for other fruit and vegetable greenhouse cultivation.

Keywords: PID fuzzy control; agricultural greenhouse; expert decision

1. Introduction

Our country is the traditional agriculture big country, along with the agricultural technology and the agricultural equipment development, has appeared the modernized technology greenhouse. In the greenhouse is mainly responsible for the impact of environmental factors to control crop growth, the environmental factors affecting crop growth include wind, soil temperature and humidity, air temperature and humidity, soil quality, light intensity, irrigation, carbon dioxide concentration and so on. Among the Asian countries, the research and application of greenhouse control technology in Korea and Japan are more prominent than in other countries [1]. In the United States, the Greenhouse Control Field has led the world, with the continuous progress of technology, greenhouse control automation

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has taken a qualitative leap [2]. Japan's vegetable greenhouses are using computers and the internet to adjust the temperature, humidity, light intensity, carbon dioxide concentration of these four environmental factors in real time [3]. Many foreign researchers have proposed some unique control methods and new control algorithms for greenhouse control system. Chalabi ZS uses weather forecasts to mark the growing conditions of crops in greenhouses and proposes that the temperature-accumulation method can be used to set the placement point of temperature-heating devices [4]. Fisher Paul R designed and developed a greenhouse control system, using the CARE system to set the day and night thresholds for each growing period of crops in the greenhouse, and using a computer to connect to the greenhouse control system, thus the control of the temperature change in the greenhouse can be realized [5]. Körner o combined temperature and humidity in a greenhouse to develop a more sensitive and less energy-consuming greenhouse regulation system, improving and innovating the accumulated temperature control algorithm, the system designed to control temperature uses less energy and is more sensitive than the normal temperature control method, thus improving the control of the greenhouse internal environment [6-8]. By designing a fuzzy logic algorithm and an adaptive neural network fuzzy model, habibs is applied in the tomato greenhouse to realize the control system of the tomato greenhouse interior [9-11] .In the early 20th century, plastic-based greenhouses began to emerge in our country, and in the mid-to-late 20th century, computer technology was introduced into our agricultural cultivation field and the automation of greenhouse control systems began to be developed [12-15]. After the 21st century, our country's modern agricultural greenhouse automatic control entered a new development period, began to use the monolithic integrated circuit as the control main body, because the monolithic integrated circuit control programming language is quite cumbersome, it is difficult to make changes to the system when people have problems in using it, so when the system fails, people will mostly use manual operation mode, resulting in the abandonment of the automatic control module [16-18]. To sum up, in the Internet technology and automatic control technology development of today's era, greenhouse control technology has been further improved. Greenhouse-related control systems are also gradually moving towards automation, unmanned, accurate direction of development. In this paper, taking cherry planting in agricultural greenhouse as an example, using PLC to simulate and monitor the main environmental factors affecting cherry growth in greenhouse, and find the best monitoring method, therefore, it is of practical significance to ensure the quality of greenhouse planting in order to improve crop yield and promote rural development and achieve precision poverty alleviation.

2. Basic theory of fuzzy control

In the actual engineering project, PID control is the most extensive control law, also known as proportional, integral, differential control. PID controller has been developed for more than 70 years. In the field of industrial control, it involves simple algorithm and control structure. The PID controller finds a precise way to match the set value with the output value by adjusting the deviation of the system. In different control projects, there are corresponding control methods, finding the most suitable control method can make the PID controller achieve the optimal control effect. PID controller is composed of three parts: proportion, differentiation and integration. The parameters of each link are set to optimize the system control. PID control is a common feedback regulation in industrial control, which is mainly used in linear systems and systems whose dynamic characteristics do not change with time. The PID control algorithm mainly uses the input value and the data collection system feedback to compare mutually. After the comparison difference calculates the new input value afresh, this is done to maintain or achieve a baseline value for system data. PID control through the set value and the actual output of the deviation of continuous correction, so that the control system to a more accurate and more stable state [19-20]. The control mechanism is shown in Fig.1:

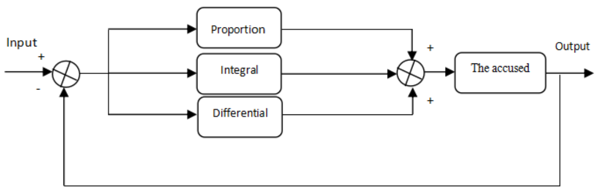


Fig.1 PID Control schematic

As can be seen from Fig. 1, PID control is the proportion of the link, the differential link, the integral link are added to the controlled object above, and then by the controlled object to the system input feedback regulation. The PID transfer function is:

$$G(s)=\frac{U(s)}{E(s)} = K_p s + K_i \frac{1}{s} + k_d s \qquad (1)$$

In formula (1), K_p is the proportional coefficient, K_i is the integral time constant and K_d is the differential time constant.

PID control can be determined by calculation, but usually in the field to debug to determine the proportion of PID control, differential, integral parameters. When the integral link is not in the low-frequency stage, the integral link will have a lag, the system will oscillate, thus affecting the stability of the system. When the system overshoots, the adjustment differential link will make the system become stable. When the control is adjusted, every parameter should be reasonable so that the PID control can achieve the optimal effect.

Because the internal environment of cherry greenhouse has the characteristics of variability, uneven distribution and hysteresis, it is difficult to carry out accurate modeling and measurement. Fuzzy control is based on the professional's experience of its operation, according to the control rules derived from past practice. Single use of fuzzy control may reduce the stability and accuracy of the control system, if the system adds PID control in fuzzy control, the formation of PID fuzzy control, system stability and accuracy can be improved more effectively [14]. The control object of this paper is cherry greenhouse. As a complex and multi-variable control system, cherry greenhouse has the characteristics of non-linearity, hysteresis and non-uniformity, it is very difficult to find out the proper proportion parameter, differential parameter and time parameter only by using PID control, fuzzy rules were used to optimize the control effect of cherry greenhouse. The control schematic is shown in Fig. 2:

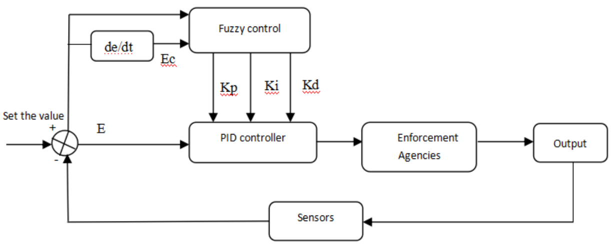


Fig. 2 Control schematic

In the control, the bigger the proportion effect of the proportion link is, the faster the adjustment time is, but the excessive proportion adjustment will reduce the stability performance of the system, and the integral link can reduce the steady-state error of the control system, the differential link is the function that affects the change rate of system signal error output signal and makes the system can predict the control ahead of time. Therefore, by using PID control and fuzzy control to select reasonable parameters, the temperature and humidity in the greenhouse can be in the range suitable for cherry growth.

3. PID fuzzy control of cherry greenhouse

3.1 Design of PID fuzzy controller

The Mamdani algorithm is chosen, which also keeps a simple computing model in high-order system and is a rule often used in fuzzy control. In MATLAB software, it is necessary to establish a model of FIS system, write fuzzy in the lower window, use fuzzy logic toolbox, as shown in Fig. 3 for fuzzy reasoning interface.

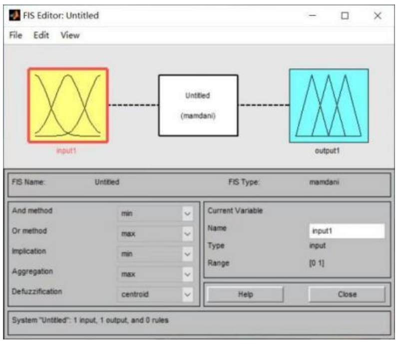


Fig. 3 Fuzzy control reasoning interface

The parameters of each signal can be modified in the fuzzy control reasoning interface, which defaults to one input signal and one output signal, it is necessary to add one input signal and two output signals in Edit. The input signal can be named E, EC, respectively, the output signal can be named *Kp*, *Ki*, *Kd* respectively. Fig. 4 is the structure diagram of the fuzzy inference system.

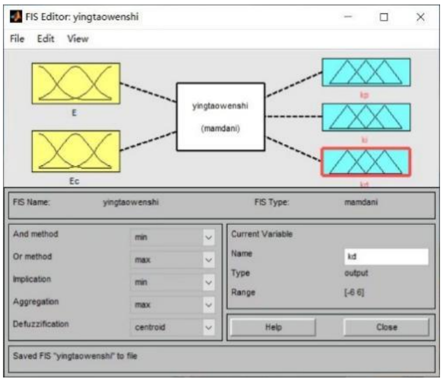


Fig. 4 Structure of system fuzzy reasoning

In the cherry greenhouse, the temperature and humidity, the two environmental factors in the change and control of the way is generally the same, so you can choose the same membership function. In general, triangular curve is used as the membership curve of fuzzy control because the system is stable and the uniform change speed is moderate, which is suitable for most fuzzy control objects. Because the error and error change rate of temperature and humidity environmental factors in cherry greenhouse cannot produce strong change under the condition of controlling, therefore, the membership of *E*, *Ec*, *Kp*, *Ki* and *Kd* is set in the form of triangular function. Fig. 5(a) shows the membership curves of the input and output variables.

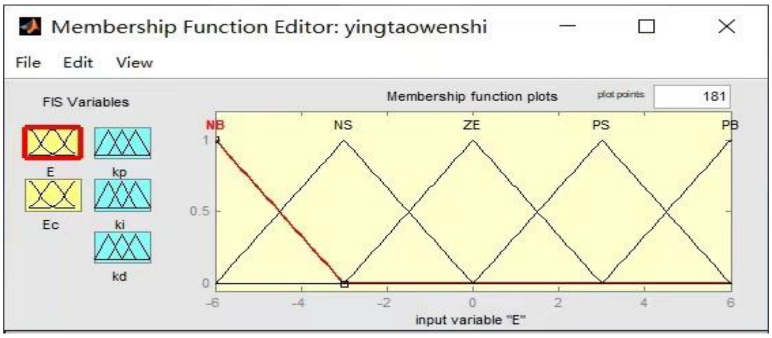


Fig. 5(a) Input Variables *E, Ec* membership function curve

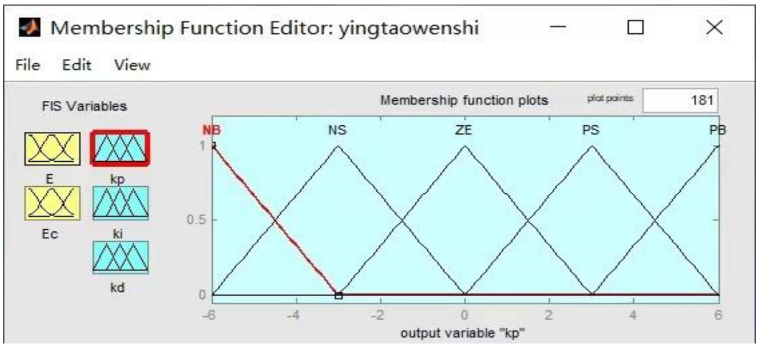


Fig. 5(b) Output variables Kp, Ki, Kd membership function curve

3.2 Fuzzy rule design

In the fuzzy rules page to edit the fuzzy rules, fuzzy rules variables were NB, NS, ZE, PS, PB five fuzzy language subsets, a total of 25 fuzzy rules can be designed, as shown in Fig. 6:

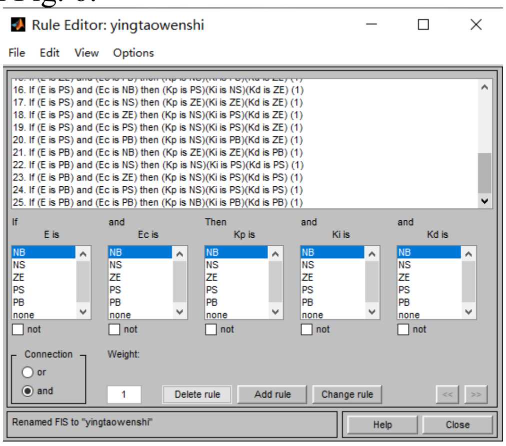


Fig. 6 Fuzzy rule editing

After establishing the fuzzy Rules, you can click on the Rules and Surface in View to see the integrity of the fuzzy Rules, and whether the information contained is comprehensive, which represents the two-dimensional View model and the three-dimensional View model, respectively, fuzzy rules can be displayed intuitively. Fig. 7 shows the fuzzy rules for the two-dimensional view model, Fig. 8 shows the fuzzy rules for the *Kp*, *Ki*, and *Kd* three-dimensional view models:

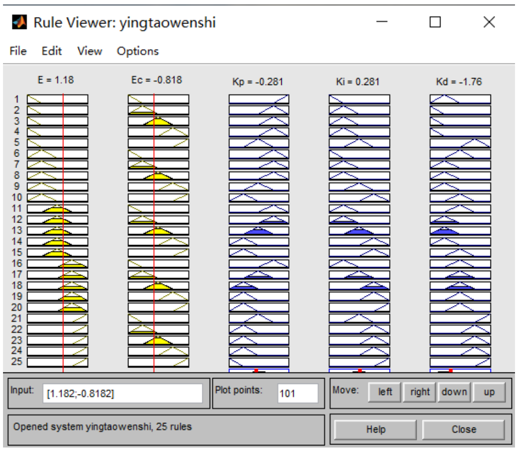
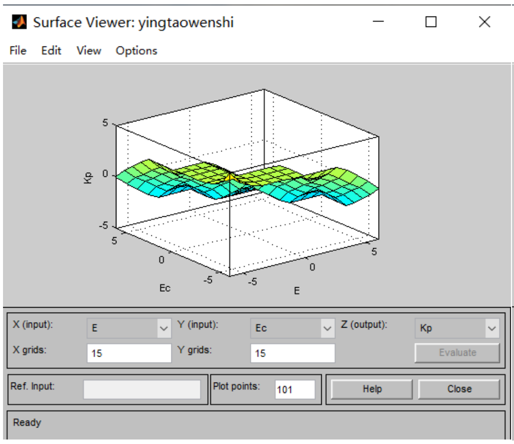


Fig. 7 Fuzzy rules for two-dimensional view models



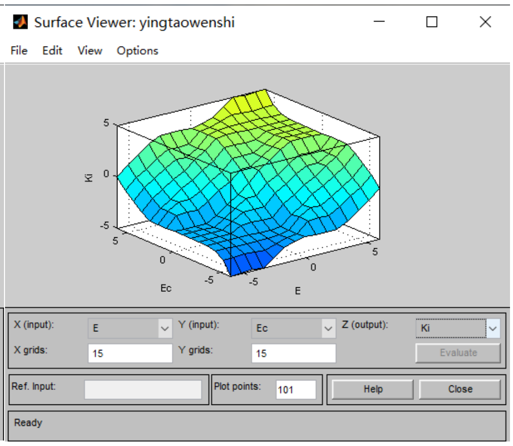


Fig. 8(a) *Kp* three-dimensional view model Fig. 8(b) *Ki* three -dimensional view model

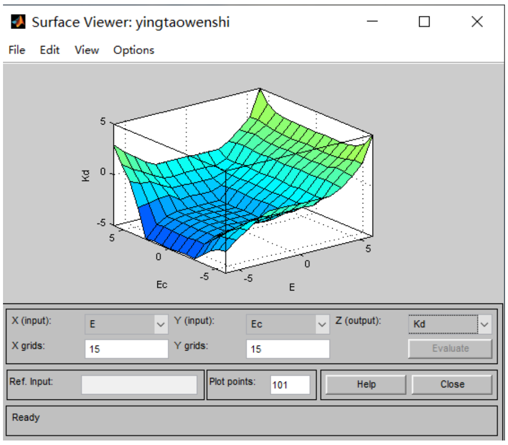


Fig. 8(c) *Kd* three -dimensional view model

4. **PID fuzzy control effect analysis**

Taking temperature control as an example, three control methods of fuzzy control, PID control and PID fuzzy control are designed respectively.

4.1 Temperature Fuzzy control

The application column of Simulink is found in MATLAB software, the simulation structure chart of fuzzy control is created, the transfer function is adopted first-order system, and the transfer function formula suitable for greenhouse temperature control is found through relevant literature:

$$G(S) = \frac{2.7}{8.2S+1} \tag{2}$$

The fuzzy controller uses a step signal with an amplitude of 22 as the target temperature input of the fuzzy controller, the output of the fuzzy controller is scaled to a suitable range by an operation circuit, and the simulation result is obtained by the transfer function. Fig. 9 is the simulation structure of the fuzzy control.

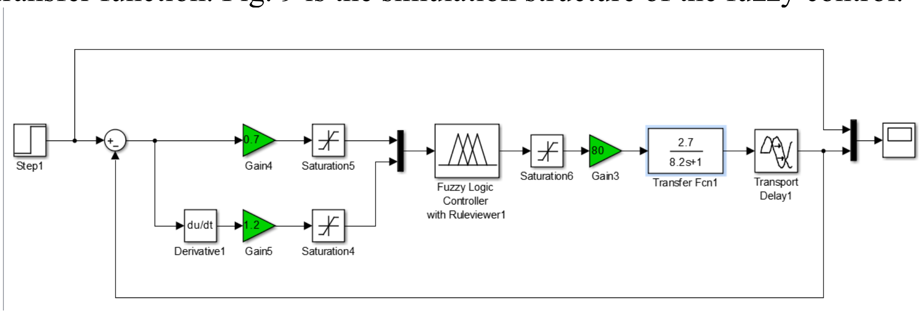


Fig. 9 Simulation structure diagram of fuzzy control

The simulation results are shown in Fig. 10. The black line is the set value of temperature, and the red curve is the output value. The step changes at the beginning of the simulation, and the set value is 22 ° c. the output value of the system begins to rise after a delay of 30 seconds, after 130s, it began to exceed the set value, appeared overshoot, began to carry on the steady-state regulation, the regulation time was 500s, infinitely approaching the target value.

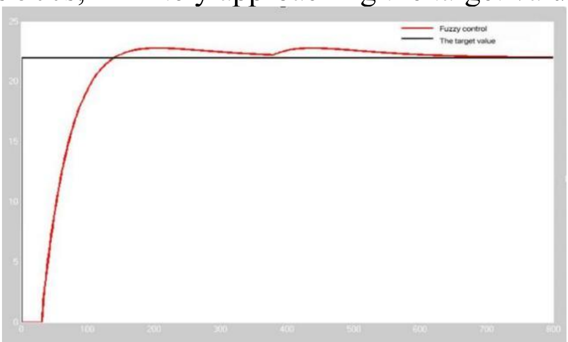


Fig. 10 Simulation results of fuzzy control

4.2 PID control

The application column of Simulink is found in MATLAB software, and the structure chart of PID control simulation is created, the PID controller uses a step signal with an amplitude of 22 as the input of the PID controller's target temperature, and then outputs the PID controller's target temperature through the proportional, differential, integral and amplification circuits, the control value is scaled to a suitable range by an operation circuit, and the simulation result is obtained by the transfer function. Fig. 11 is the PID control simulation structure.

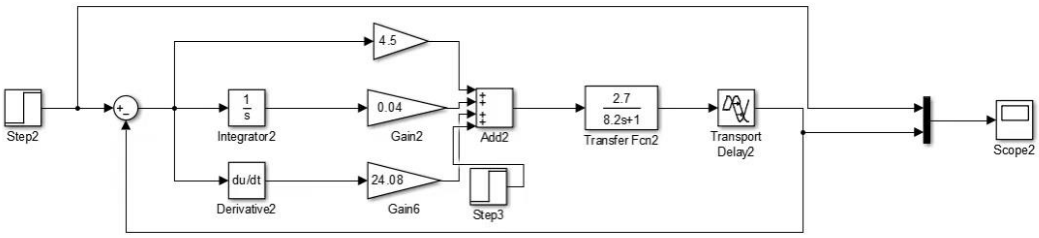


Fig.11 Simulation structure diagram of PID control

The simulation results are shown in Fig. 12. The black line is the set value of temperature and the purple curve is the output value. The step changes at the beginning of the simulation and the set value is 22 ° c. the output value of the system begins to rise after a delay of 30 seconds, after 60s, it begins to exceed the set value, and overshoot occurs. After 100s, it reaches the peak of overshoot, and the curve begins to decline.

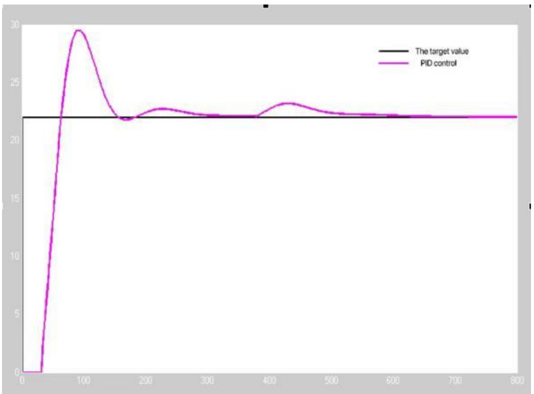


Fig. 12 Simulation results of PID control

4.3 PID fuzzy control

To create the PID fuzzy control simulation structure chart, the transfer function uses the first-order system, the transfer function uses the Formula 1, the PID fuzzy controller uses a step signal with an amplitude of 22 as the target temperature input of the PID fuzzy controller, then the analog error and error rate are carried out by the circuit of proportion, differentiation, integration and amplification. The output of the fuzzy controller is scaled to a suitable range by an operation circuit, after obtaining the simulation results through the transfer function, fig. 13 is the PID control simulation structure diagram.

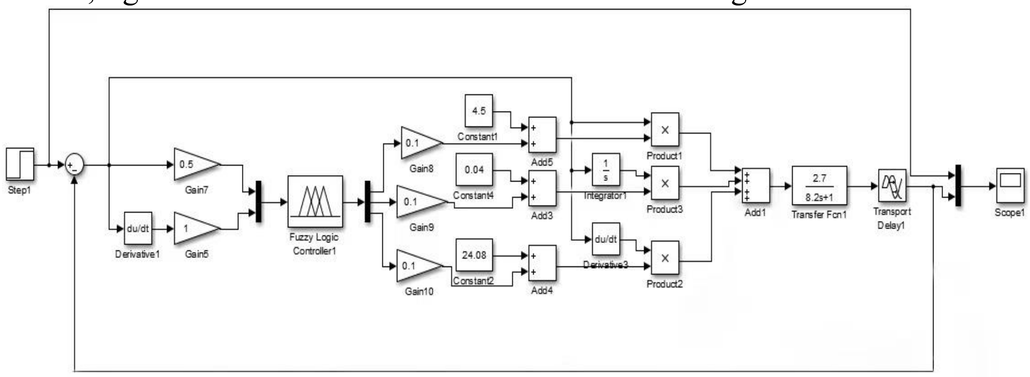


Fig.13 Simulation structure diagram of PID fuzzy control

The simulation results are shown in Fig. 14. The Blue Line is the set value of temperature and the purple curve is the output value. The step changes at the beginning of the simulation and the set value is 22 ° c. the system output value begins to rise after a delay of 30 seconds, after 80s, it begins to approach the set value, without overshoot, the curve begins to be stable and approaches the target value infinitely.

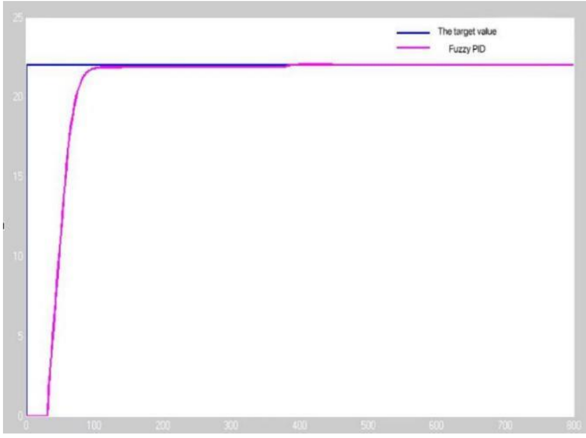


Fig.14 Simulation results of PID fuzzy control

4.4 Results analysis

Three control methods of fuzzy control, PID control and PID fuzzy control are designed. In order to compare more accurately, the three control methods take temperature as an example, using the same transfer function, the simulation results of the three control methods are put under the same oscilloscope, the characteristics of each control simulation curve can be seen more clearly. It can be seen from Fig. 15 that the rising time of fuzzy control is long, but the error affects the stable regulation and the oscillation easily affects the precision. PID control rise time is fast, but there is overshoot, in the actual control, time-varying is not good, performance is not good, poor adaptability. The combination of PID control and fuzzy control and the design of PID fuzzy control technology can keep the rising time of PID control, ensure the accuracy and ensure the adaptability of fuzzy control, by means of fuzzy inference rules and adjusting PID parameters, the changes of controlled plant can be better controlled, and the greenhouse control system can be better controlled.

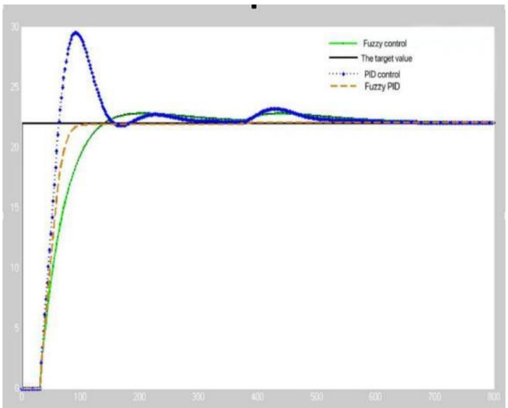


Fig. 15 Comparison of three control methods

5. Expert rule design for Cherry Greenhouse

Cherry is a kind of fruit tree with good economic benefit in the deciduous fruit trees of North China. Cherry trees are native to the Yangtze River valley, so the optimum temperature of cherry greenhouse should be adjusted according to the growth of cherry. There are four factors that affect the optimum temperature for cherry growth: (1) cherry varieties: different varieties of cherry have different range of temperature requirements, cherry varieties suitable for 20-26 ° C can be divided into three grades: 1,2 and 3. (2) age of Cherry Trees: the age of Cherry Trees is about 70 years, so the demand of temperature for cherry trees of different ages has different range. The age of cherry trees suitable for 20-26 ° C can be divided into 1,2 and 3 grades. (3) the growth cycle of Cherry: the growth cycle of cherry can be divided into growth period, flowering period and mature period, the growth cycle suitable for 20-26 ° C can be divided into three grades: 1,2 and 3. (4) the soil condition of cherry growth: the demand of cherry growth temperature is different in different soil quality, which can be divided into 1,2 and 3 grades. The temperature is the parameter to be controlled in greenhouse. The influence of each factor on the optimum temperature is discussed. Firstly, the evaluation coefficient of each factor's influence on the optimum temperature is established according to the classification. Using the SANTY1-9 scaling method , the effects of four factors on the optimum temperature are divided into nine grades from high to low according to experience, the formation of the importance judgment matrix is shown in Table 1. The factors of F 1 ~ F 4 are variety, tree age, growth cycle and soil respectively.

Table 1

The importance of each control mode on the influence of temperature judgment matrix table

Ways of regulation and control	F1	F2	F3	F4
F1	1	2	1/3	3
F2	1/2	1	1/7	2
F3	3	7	1	7
F4	1/3	1/2	1/7	1

According to the judgment matrix, the weight coefficient of the influence of each regulation mode on the temperature is calculated, and the column vector is normalized to get:

$$\dot{W}_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij} \tag{3}$$

Where, a_{ij} is the element of the judgment matrix； n is the order of the judgment matrix;

Sum the lines of $\dot{W}_{ij}$:

$$\dot{W}_{i} = \sum_{j=1}^{n} \dot{W}_{ij} \tag{4}$$

Normalize $\dot{W}_i$ to:

$$W_i = \dot{W}_i / \sum_{i=1}^{n} \dot{W}_i \tag{5}$$

$W(W_1, W_2, W_3, W_4)^T$ That is, the control equipment on the importance of the impact of temperature evaluation factor: $W = [0.11, 0.05, 0.41, 0.39]$

Then the consistency of the evaluation index was judged. According to the approximate value of the largest characteristic root and the consistency index *CI*, the result λ_{max}=6.7, CI=0.062<0.1, therefore, it is considered that all the factors designed in this study have a satisfactory consistency on the expert level of the optimal temperature.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(FW)_i}{W_i} \quad (6)$$

$$CI = \frac{\lambda_{max}-n}{n-1} \quad (7)$$

Among them, *F* is the judgment matrix, λ is the approximate value of the largest eigenroot of the judgment matrix, and *CI* is the consistency index of the judgment matrix.

6. Conclusion

PID fuzzy control of cherry greenhouse is designed, fuzzy rules are displayed by MATLAB software, and simulation debugging is carried out at the same time, and the effect of fuzzy control and PID control is compared, the characteristics of PID fuzzy control, such as fast response time and high precision, are compared, and the expert rule decision is designed.

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REFERENCES

[1] Cheng Rui, Wang Shuangxi. Research and application of intelligent control system for greenhouse environment. Journal of Shanxi Agricultural Sciences, 2014, 42(2):203-205.

[2] Zhang Lingmei, Wang Jinhe. Experience and enlightenment of quality management of agricultural products in Israel. Southern Agriculture, 2021, 15(20):160-162.

[3] Lesk C., Rowhani P., Ramankutty N. Influence of extreme weather disasters on global crop production. Nature 2016;529:84-7.

[4] Cañadas J., Sánchez-Molina J. A., Rodríguez F, et al. Improving automatic climate control with decision support techniques to minimize disease effects in greenhouse tomatoes. Information Processing in Agriculture,2017,4(1):50-63.

[5] Morales F., Pascual I, Sánchez-Díaz M., Methodological advances: using greenhouse to simulate climate change scenarios. Plant Science, 2014, 226:30-40.

[6] Habib S., Akram M., Ashraf A., Fuzzy Climate Decision Support Systems for Tomatoes in High Tunnels. International Journal of Fuzzy Systems, 2017, 19(3):751-775.
[7] Wang Yun, Application of PLC in mechanical and electrical control devices. Modern Manufacturing Technology and Equipment, 2022, 58(07):201-203.
[8] Cañadas J., Improving automatic climate control with decision support techniques to minimize disease effects in greenhouse tomatoes. Information Processing in Agriculture, 2017, 4(1):50-63.
[9] Maeda, D., A Review of Japanese Greenhouse Cucumber Research from the Perspective of Yield Components. The Horticulture Journal, 2021, 90(3):263-269.
[10] Liang Erwen, Yu Qi, Xu Bo, et al. Design and simulation of material trolley control system based on WinCC. Power Tools, 2022, (02): 20-25.
[11] Sen Wang, Pratteek-Das, Zhong-shuai Wu. High-energy-density microscale energy storage devices for Internet of Things. Scientific Bulletine, https://doi.org/10.1016/j.scib.2024.01.0122095-9273/
[12] Chuang Yang, Anni Luo, Hai-Ping Lu, et al. Diurnal regulation of alternative splicing associated with thermotolerance in rice by two glycine-rich RNA-binding proteins. Scientific Bulletine, 2024, (69):59-71.
[13] Li Pingping, Chen Meizhen, Wang Jizhang, et al., Research on Development and Data Synchronization of Greenhouse IoT Measurement and Control Management System. Transactions of the Chinese Society for Agricultural Machinery, 2015, 46(8):224-231.
[14] Yu Caiyun, Li Shuguang, Climatic factors affecting yield in cherry planting. Modern Agricultural Research, 2021, 27(01):107-108.
[15] Millan Sandra, Campillo Carlos, Casadesus Jaume, et al. Automatic Irrigation Scheduling on a Hedgeroew Olive Orchard Using an Algorithm of Water Balance Readjusted with Soil Moisture Sensosr. Sensors, 2020, 20(9):2526.
[16] Liu Xing. Siemens Launches TIA Portal V15 Engineering Software Platform: Focus on Application, Digitalization and Efficiency. Electrical Engineering, 2018, 19(03): 5.
[17] Yu Caiyun, Li Shuguang, Climatic factors affecting yield in cherry planting. Modern Agricultural Research, 2021,27(01):107-108
[18] Zhang Tingbao, Liu Gaoshang, Liu Mengjin. Cherries are delicious and difficult to plant, and finding the "spleen" is the key. Northwest Horticulture (Fruit Trees), 2018, (06): 33-35.
[19] Yaser Hoseini, Manochehr Shiri Janaghard. Using a Fuzzy Control System to Optimise the Parametric Method for Selecting the Appropriate Irrigation System. Research in Agricultural Engineering, 2019, 65:70-75.
[20] Aarti Kochhar, Naresh Kumar, Wireless Sensor Networks for Greenhouses: An End-to-end Review. Computers and Electronics in Agriculture, 2019, 163:104887.