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Analysis and Prospect of AI's Participation in Greenhouse Environmental Regulation

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Abstract. Greenhouse technology can achieve high-quality and high-yield crops and promote the development of the agricultural economy. With the rapid development of science and technology, measurement and control technology, computer technology and other technologies have been applied to improve and innovate greenhouse facilities, and different control technologies are also being updated. Artificial intelligence technology can achieve multi-factor efficient rapid collection and rapid linkage regulation of the greenhouse environment based on system data, injecting new vitality into greenhouse technology. Although not yet perfect, intelligent greenhouse technology has great prospects and is worth exploring and trying. It is one of the future development directions of facility agriculture.

Keywords: Artificial intelligence, Greenhouse, Facility agriculture, Environmental regulation

1. Introduction

During the long course of evolution, people learned to cultivate, and the growth of crops was constrained by various factors in the environment such as temperature, humidity, light, and CO2 concentration, which led to people living a life of "relying on the weather" in the early days. Under the pressure of food and clothing problems, greenhouses began to take shape two thousand years ago. In the Tang Dynasty, this concept was further developed into the technology which is called Tang flower art. This technology uses methods such as applying hot water and burning fuel in the ditch under the flower pot stand to increase the indoor temperature, so that the flowers could bloom earlier out of season. The development of science and technology has promoted the rapid progress of greenhouse technology. In the 1870s, thanks to the improvement of policies and the advancement of glass manufacturing technology, greenhouse development officially entered a golden age. In the following 20th century, polyethylene plastic film began to gain popularity, and plastic greenhouses were widely used in agricultural production. People ended the limitation of "relying on the weather" and began to be able to simply adjust and change environmental factors to produce crops across seasons.

Greenhouse technology has significant advantages such as off-season production, increased yield, and intensive production, and is dominant in today's agricultural development. The development of greenhouse technology has pushed people to move from "relying on the weather" to self-production, and there is still great potential and a bright future in facility agriculture technology. Since the

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1970s, with the rapid development of computer technology, remote control technology, sensor technology and other fields, various intelligent instruments have been manufactured and applied. AI technology, with its advantages of intelligence and efficiency, has rapidly entered the research and development of greenhouse control technology. The rapid advancement of science and technology has gradually brought the mainstream greenhouse technology closer to high yield, intensive production and intelligence.

Since the beginning of the 21st century, with the expansion of market demand for crops and the adjustment of agricultural planting structure in China, facility agriculture technology in China has developed rapidly. As of the third national agricultural census, greenhouse land covers 334 thousand hectares and plastic greenhouse land covers 981 thousand hectares [1]. However, due to the late start of greenhouse facility technology in China, the related facilities in China are relatively old and backward, with a low level of informatization, and there is still a considerable gap compared with developed countries in terms of output and other aspects.

Unlike manual single-factor regulation deployed empirically, AI-involved smart greenhouses use smart sensor technology to collect environmental conditions, rely on computer technology to process and process the information, and automatically make regulation based on the interaction of the input conditions. The integration and high efficiency of the greenhouse make it highly consistent with the demands of today's market. Analyzing the requirements of different crops for environmental factors such as temperature, humidity, light and CO2 concentration, and how these environmental factors interact with each other is of great [2]. However, due to the large amount of empirical data required and the high demand for system computing power and algorithms, intelligent greenhouse technology still needs to be further developed and researched, and has broad room for development.

2. The intelligent greenhouse control technology that is widely used nowadays

2.1. PID control technology

PID control, or proportional-integral-differential control [3], is a feedback control technology that works in linkage with sensors and control devices to dynamically adjust environmental factors such as temperature, humidity, and CO_2 concentration based on the deviation of the collected data from the target value to stabilize the environmental factors in the greenhouse around the target value. PID technology has a long history of use in greenhouse regulation.

PID technology consists of three steps: proportional, integral, and differential. Proportional (P) is the adjustment of the intensity of the adjustment quickly based on the deviation from the target value when the error occurs, but the control stage is prone to deviation repetition; The integration (I) stage adjusts the intensity of the "static deviation" that the proportion cannot eliminate based on the accumulated deviation time; Differential (D) regulates the intensity of the environmental factor by calculating the rate at which the prediction error changes to prevent excessive regulation from causing the deviation to increase in the opposite direction.

However, since PID technology is linear regulation, it is difficult to regulate both parametric regulation and nonlinear environments. At the same time, because it takes a long time to analyze and regulate environmental factors, it is difficult to implement regulation in the greenhouse environment. Therefore, the ability to respond to emergencies is weak [4]. When factors such as temperature change suddenly, it is difficult to make rapid regulation, which is highly likely to cause damage to crops and result in a decrease in yield and quality.

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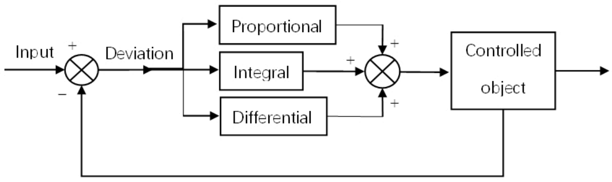

Figure 1. PID control principle

2.2. Fuzzy control technology

Fuzzy control is a nonlinear control method that does not require the establishment of precise models. The principle of this technology is to summarize relevant sets based on planting experience and artificial regulation ideas, and use language rules to judge the greenhouse environment and make corresponding adjustments. This kind of control enables the system to better cope with complex and changeable environments [5].

In a fuzzy controller, fuzzy control is divided into three stages: fuzzification, fuzzy reasoning, and defuzzification.

The process of fuzzification involves converting the exact data collected by the sensor into fuzzy concepts and membership degrees through "membership functions," which simulate the process of judging the degree of conditions in human decision-making.

Then the input is compared and reasoned with a rule base composed of planting experience and expert theory according to IF-then logical rules, and the membership degree of the resulting input data is matched with the rule. if the membership degree with a certain rule is greater than zero, that rule will be activated.

Since the operation of the equipment requires specific parameters rather than fuzzy concepts, the activated concept instructions cannot be directly read. Therefore, a series of algorithms such as the "center of gravity method" and "maximum membership degree method" need to be used in the defuzzification to convert fuzzy instructions into precise parameters for the control of the equipment. Then, after this series of processes, the defuzzification process is carried out to regulatethe controlled system [6].

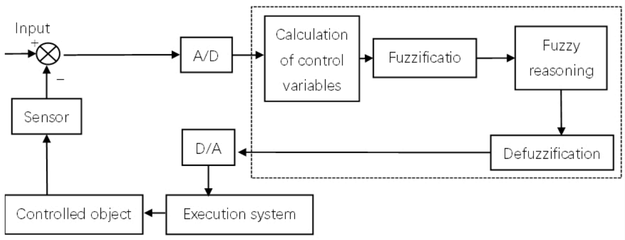

Figure 2. Fuzzy control

Because fuzzy control requires the process of fuzzifying and defuzzification data, it is computationally intensive and complex, consuming a large amount of computing resources, which affects efficiency and rate. At the same time, due to the inability to edit online, the optimization of fuzzy rules and the regulation of unknown empirical environments pose significant challenges.

Taking the two commonly used control methods in greenhouses as examples for analysis, it can be found that the traditional greenhouse control methods have some areas that still need improvement, such as limited ability to control complex conditions, inability to meet the demand for

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real-time control, low degree of intelligence, and reliance on human labor; The temperature control system based on the fuzzy self-tuning PID algorithm that modifies the PID parameters in real time according to the temperature deviation studied by Yu Huanle [7] has problems such as large overshoot and low control accuracy [8]. Therefore, in combination with the development of science and technology, AI-enabled greenhouse regulation technology is used to inject new vitality into aspects such as real-time regulation and fineness of the control system.

3. AI-enabled greenhouse control

3.1. Benefits from AI empowerment

In today's rapidly advancing science and technology, AI is at the forefront of science and technology. It is a technology agent with strong data analysis capabilities, autonomous and continuous learning capabilities, decision-making capabilities, etc., capable of performing multiple functions such as analyzing data, building models for learning independently to link multiple technical collaborations, building models and making intelligent decisions, And because of these significant advantages, AI has begun to enter various industries and, in conjunction with Internet of Things technology, promote the intelligent transformation of industries, improve the quality and efficiency of production and life, cover multiple fields of industrial empowerment and inject new vitality, and drive the digital transformation of society.

Compared with the traditional greenhouse control model, the use of AI in greenhouse control can obtain various indicators of crop growth at different time periods through sensors, such as the degree of leaf curling and respiration intensity. Based on this, real-time analysis and dynamic response can be made to the needs of crops at different growth stages and under different environmental conditions, significantly improving the accuracy and adaptability of control. At the same time, under the precise regulation of AI technology, crops can be within the optimal range as much as possible at all times, rather than fluctuating sharply around the range, thereby increasing crop yield and quality.

In addition to analyzing the growth of crops in real time, AI can also regulate the indoor environment in real time, collect data, estimate crop needs, link to the Internet of things to input changes in the external environment in advance for regulation, and even in the case of emergencies, get the news in a short time and quickly calculate the best response plan and then make the most appropriate regulation and the stability of the environment.

In addition, AI's autonomous analysis and its ability to perform intelligent operations in place of human labor have alleviated the stress on staff involved in high-intensity tasks such as multiple inspections and dedicated analysis in traditional regulation, significantly reducing labor costs.

In terms of resource utilization, the use of AI regulation significantly improves the utilization rate of resources and reduces resource waste. Take water resources as an example. According to statistics issued by the Ministry of Water Resources, the total national water consumption in 2019 was as high as 602.12 billion cubic meters, of which the total agricultural water consumption accounted for 368.23 billion cubic meters, accounting for 61.2% [9]. China's total water resources amount to 2.8 trillion cubic meters, ranking sixth in the world, but the per capita water resources (2,200 cubic meters) are only a quarter of the world average. China's water resources are also characterized by uneven regional distribution, frequent droughts and floods, mismatch between water resources and arable land resources, and tight water resources, which restrict economic development [10].According to statistics and summaries of domestic and foreign data, the use of smart greenhouses (such as those based on LSTM neural network models) has increased the utilization rate of water resources in greenhouses from only 30%-40% to 50%-70%, achieving rational

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irrigation and developing water-saving agriculture, which is of great significance for alleviating the shortage of water resources in China. Not only that, but the increasing demand for food has made the development of new agriculture with high-quality production a hot topic at present. And the development of AI is empowering with technology, providing new opportunities for this topic [11].

Table 1. Comparison of PID control, fuzzy control and AI enabling

Technology	Advantages	Disadvantages
PID	Simple principle; strong stability for single parameters.	Weak response to emergencies; fails in non-linear environments.
Fuzzy	Handles complex/linear environments; anti-interference.	Subjective (expert-dependent); difficult to optimize in real-time.
AI-Enabled	Real-time precision; unmanned operations; cross-tech integration.	High maintenance/equipment costs; data and talent shortages.

3.2. The integration of AI with various regulation technologies promotes innovative and integrated development

In addition to AI technology itself being a new opportunity for greenhouse regulation, AI also empowers other regulation technologies. Take the Internet of Things technology, which is deeply integrated with AI and mutually empowered, as an example.

The Internet of Things is a network that connects everything. It refers to the real-time acquisition of information or processes of objects or processes that need to be connected through various sensors and information collection technologies such as radio frequency identification (PFID) and global positioning system (GPS), and the intelligent collection, intelligent identification, and intelligent processing of objects or processes through various network access.

The system architecture of the Internet of Things can be divided into four categories: the perception layer, the network layer, the platform layer, and the application layer; the perception layer is the use of various sensor technologies for identification and information collection; The network layer is responsible for transmitting the information collected by sensors; The platform layer analyzes, manages and stores the obtained information; The application layer is responsible for transforming the information into a service form [12].

Applying Internet of Things technology to the regulation of the greenhouse environment enables precise collection and aggregation of the greenhouse environment, as well as simultaneous management and regulation of multiple greenhouses; AI technology can process and analyze massive amounts of data, learn autonomously from the analysis results of historical data, build models, make intelligent decisions, and optimize decisions. When combined with greenhouse regulation, it enables precise control of the greenhouse environment, rapid detection of various environmental conditions including emergencies, timely decision-making, multi-zone intensive management, enhanced management efficiency, and increased crop yield [13].

The Jinan Kebai Smart Agriculture Park has achieved full digitalization of Internet of Things technology and precise control of artificial intelligence technology. The farm is located in Laiwu District, Jinan City, Shandong Province. The annual output of the wax apple in the park is 4,500 kg per mu, with soluble solids at 14%, which is more than 50% higher than the original production area. Papaya yields an average of 5,000 kilograms per mu, with more than 13 percent of soluble solids, which is 25 percent higher than its origin. Both are southern fruits grown in the north and have achieved such excellent results thanks to the application of a series of Internet of Things intelligent greenhouse control technologies:

(1) The industrial park has equipped each greenhouse with a relatively complete set of sensors to collect basic data in the greenhouse and characteristic data during the growth process of crops, such as leaf temperature and humidity, runoff, leaf area, micro-variation parameters of fruits and so on, in

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order to collect relevant information on the impact of the environment on crops at each period and the growth status of crops, providing a basis for decision-making.

(2) The industrial park uses GPRS/GSM networks, etc. to transmit information to the data processing center. This wireless transmission significantly reduces the requirement for the number of central base stations and saves space and financial costs.

(3) After obtaining the data, the data center needs to simultaneously control multiple devices at high frequency and jointly grasp them. The computing power and autonomous decision-making ability of AI can ensure the smooth operation of the complex logic of the intelligent greenhouse. Based on the long and massive data collected, AI performs data screening and in-depth analysis, intelligently creates control models, achieves efficient and convenient management, and can also predict pests and diseases in advance based on the data, providing decision-making for plant protection management.

(4) In terms of water and fertilizer, the application of this technology can achieve high-frequency word supply similar to "three meals a day" that traditional regulation methods cannot achieve, providing conditions for crops to continuously absorb water and fertilizer. At the same time, data shows that compared with traditional methods, this model can save 70% of water and increase fertilizer utilization by more [14].

The Kebai Smart Agriculture Industrial Park has achieved real-time care of crops and precise management of equipment by applying the Internet of Things intelligent regulation technology, and has achieved excellent results in both yield and quality, demonstrating the broad prospects of smart agriculture.

4. Conclusions

The core of AI's involvement in regulating the greenhouse environment lies in the efficiency and autonomy brought by its algorithms, which requires a large amount of data and sensors to ensure the correctness of decisions. The agricultural production cycle is long and varies with climate conditions and regional characteristics, and it takes multiple cycles to obtain high-quality data. Not only sensors, but deploying the entire AI system requires corresponding equipment support. The complex and changeable environment of agricultural planting further increases the requirements for the precision and sensitivity of the equipment, and the large amount of computation in the complex environment makes real-time adjustment unable to achieve the expected response speed. In addition, the equipment needs regular maintenance checks, All these factors contribute to the high initial construction costs of smart agriculture, the long and high maintenance costs in the later stage, and the long capital return cycle, making it difficult to be widely popularized in China at present.

In addition to hardware reasons, the generality of current AI models is affected by dimensions, altitudes, species, etc. Trained AI overadapts to training conditions and cannot be effectively applied to other conditions to achieve the accuracy of intelligent decision-making. And for unexpected situations that are not stored and analyzed in the AI database, AI struggles to handle them correctly and promptly, not as well as experienced agricultural growers.

The above-mentioned AI models, from training and construction to application and maintenance, cannot do without relevant professionals. There is a shortage of compliant talents in this regard in China, and due to constraints such as funds and time, it is impossible to widely provide overall training equipment knowledge and operation skills for farmers who are currently engaged in traditional agricultural planting to cultivate "new farmers".

Although AI's participation in greenhouse regulation still faces multiple problems such as popularization, model training, and data shortage at present, with the continuous breakthroughs in

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multiple dimensions of technology, it will drive the rapid development of agricultural digitalization with multiple advantages such as high degree of intensification, reduced labor costs, improved crop yield and quality, and efficient real-time data collection and processing. To achieve the widespread adoption of modern agriculture in our country, contribute to rural revitalization and promote green development [15].

References

[1] Sun Yan, Yuan Yixin, Ge Hengjun, et al. Spatial pattern and evolutionary trends of agricultural greenhouse facilities in China from 2010 to 2022 [J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2025, 41(18): 291-299. (in Chinese with English abstract)

[2] Shi Ling, Ren Yucan. The Application of Control Technology inEnvironment Control of Greenhouse [J]. Modern Agricultural Equipment, 2007, (01): 34-39.

[3] Wang Hongfei, Guo Hong 'en, He Qinghai, et al. Research status and prospect of greenhouse environmental control methods [J]. Journal of agricultural engineering, 2025, 15(06): 45-53.DOI: 10.19998/j.cnki.2095-1795.202506308.

[4] Bao Yidong, Chen Guo, Zhong Guorong. Intelligent control system for temperature and humidity in greenhouses based on PID algorithm [J]. Digital Communications World, 2020, (08): 74-75.

[5] Wang Lina, Cao Jian 'an, Wang Lianhua, et al. Design of Green House Climate Controller Based on Fuzzy Control [J]. Journal of Chinese agricultural mechanization, 2024, 45(07): 75-80. DOI: 10.13733/j.jcam.issn.2095-5553.2024.07.012.

[6] Hu Jin, Yang Yongxia, Li Yuanfang, et al. Analysis and prospect of the environmental control systems for greenhouse [J].Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2024, 40(1): 112-128. (in Chinesewith English abstract)

[7] Yu Huanle, Fang Yongfeng. Greenhouse based on fuzzy self-tuning PID temperature control system design and simulation [J]. Journal of jiangsu agricultural science, 2016, 44 (12) : 383-386. The DOI: 10.15889 / j.i SSN. 1002-1302.2016.12.118.

[8] Wang Zhihua, Xu Heng. Temperature Control System for Agriculture Greenhouse Based on Adaptive Fuzzy PID [J]. Chinese Journal of Agricultural Sciences in Shaanxi, 2025, 71(09): 88-93.

[9] China Water Resources Bulletin [J].Water Resources Development and Management, 2025, 11(07): 2.

[10] Zhang Xiuqin. Response Mechanisams of Chines Agricultural Water Resources Management under Climate Chang [D]. Northwest A& F University, 2013.

[11] Wang Guoan, He Wenle , Xu Sumei. Research on the Application of Internet of Things Technology in Intelligent Agriculture Management, 2025, 23(19): 183-185.DOI: 10.16661/j.cnki.1672-3791.2503-5042-7853.

[12] Wang Pengyuan. Application of Internet of Things Technology in Intelligent Agriculture [J]. Journal of application of integrated circuits, 2025, 42(03): 140-141.DOI: 10.19339/j.issn.1674-2583.2025.03.052.

[13] Liu Yanhui, Yang Yi, Zhou Honglei, et al. Artificial Intelligence-Enabled Food Security Information Services: Influencing Factors , Service Models, and Implementation Paths, 1-10 [2026-01-29].https: //link.cnki.net/urlid/11.1762.G3.20251208.1534.004.

[14] Cao Yaopeng, Liu Houcheng. Big Data and Agricultural Internet of Things Technology in Environmental Control of Smart Greenhouses: A Case Study of Jinan Kebai Smart Agriculture Industrial Park [J]. Agricultural engineering technology, 2021, 9 (4) : 21-26. DOI: 10.16815 / j.carol carroll nki. 11-5436 / s. 2021.04.003.

[15] Zhang Zhaoqing. China's agricultural innovation accelerates AI will Bring disruptive Impact [N]. Economic Information Daily, 2026-01-26(005).