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DEVELOPMENT STATUS AND TREND OF PLANT FACTORY INTELLIGENCE IN CHINA

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Abstract

This paper analyzes the development status and trend of intelligent plant factories in China, hoping to give enlightenment to the development of plant factories in Ukraine or other countries. With the development of modern agricultural science and technology, plant industrialized production has become the preferred development mode of modern agriculture. At present, the plant factory is not highly intelligent and is in the stage of semi artificial intelligence. Most of the production operations and management are completed manually, which is difficult to manage, high cost and low efficiency. Process and analyze the real-time monitoring data, dynamically generate the management decision-making model, intelligently control the integrated irrigation equipment of water and fertilizer, the automatic recycling system of nutrient solution and other equipment and systems, and comprehensively intelligently regulate the LED artificial light, temperature and humidity, CO_2 concentration and air flow. These require highly intelligent facilities and equipment to jointly provide the most suitable growth environment for crops. Therefore, the effective integration of agricultural machinery and agronomy is the key to realize the intelligent management of plant factories. The deep integration of agricultural equipment with artificial intelligence and information technology to improve its automation and intelligence level will help to solve the problems existing in the industrialization of plant factories and the scale of crop planting.

Key words*: intelligent agriculture, plant factory, sustainable agriculture, urban agriculture, vertical farm.*

INTRODUCTION

Due to the rapid growth of population, large-scale expansion of cities, decreasing cultivated land, shortage of land resources, global spread of epidemic diseases, frequent extreme climate, pesticide abuse and serious biological pollution, organic food crop production, food supply, fruit and vegetable raw eating security are facing great threats and challenges. On the other hand, with the continuous improvement of people's living standards, the requirements for food hygiene, nutrition, health and greens are higher and higher. At present, a plant factory is one of the effective methods to solve the above contradiction. Plant factory refers to an efficient agricultural system that realizes the annual planned production of crops in vertical three-dimensional space through high-precision environmental control under completely closed or semi closed conditions (Yang, 2019). Artificial light plant factory refers to a plant industrial production facility with artificial light, heat insulation and almost closed warehouse structure (Kozai, 2013). Compared with open-air agriculture, the annual crop productivity of protected planting with the same floor area has increased by one order of magnitude (Mitchell, 2004), and the productivity of multi-layer indoor crop production has increased by two orders of magnitude (Kozai et al., 2015). This environmentally controlled agriculture is called indoor agriculture, urban agriculture, vertical agriculture or plant factories all over the world and they have great potential to provide fresh and healthy agricultural products all year round without long-distance transportation and can be built in any place and climate conditions (Kozai et al., 2019). However, the plant factory has large initial investment, high power consumption, high operation cost, and the management is mostly completed manually, so the management is difficult and the management cost is also high. Therefore, how to improve the automation of production

process is the research and development trend of the plant factory.

In recent years, the plant factory has gradually realized the semi automation of the production process from sowing, seedling raising, transplanting, harvesting, handling and logistics. Models of some industrial production automation technologies have been taken over, the automatic logistics system is developed to realize the automatic handling of the seedbed in the process of transplanting and harvesting, which is conducive to reducing the work intensity of labor personnel, improving productivity and reducing production costs. However, the plant factory with weak artificial intelligence still can not meet the unmanned planting. In order to reduce labor intensity, human resource cost and damage to plant growth environment caused by frequent access of operators, intellectualization and unmanned will become an important direction for the intelligent development of plant factories.

In addition, the light, temperature, humidity, carbon dioxide and nutritional conditions required for the growth of different crops vary greatly, even if the crops of the same variety have different requirements for the environment at each growth stage. Therefore, it is impossible to control the growth process of all plants with a unified growth model, but different comprehensive regulation is required according to different crops. However, up to now, there is still a lack of fine production guidance and necessary data support in plant production practice, resulting in poor crop growth, low comprehensive utilization rate of resources and low production efficiency. Therefore, the accuracy of production management indicators and production modes is an important guarantee to improve the work productivity of plant factories.

DEVELOPMENT STATUS

At present, in the field of plant factories, many countries such as Japan, the Netherlands, the United States, Sweden, the United Kingdom, Israel, etc., are very advanced in implementing a high level of mechanization systems, automation and intelligent leadership, without a lot of manual participation and coordination. Moreover, plant factories in the form of miniaturization, household, containerization, hotel and vertical agriculture are developing rapidly, and are also developing in a more intelligent direction. In recent years, China's plant factory research progress and technological development have been very fast. By the end of 2020, more than 200 commercial plant factories, more than 600 laboratories in artificial light plants and more than 1,200 air-conditioned room laboratories have been built, which has made progress gradually, on the road to the industrialization of plant production (China Zhiyan Data Research Center, 2021). However, compared with the technical characteristics and intelligent requirements of the plant factory itself, there is still a big gap (Zhang et al., 2021). Most of the existing equipment and systems come from solar greenhouses and other technologies in the field of facility agriculture. There is still a huge room for improvement in the hardware and software technologies required for the application environment of the plant factory. Researchers predict that in the not-too-distant future there will be creative breakthroughs in scientific and technical research to improve the automation of the efficient operation of plant cultivation (Zhang et al., 2019). In terms of hardware, due to the complexity of crop growth process, plant factory automation equipment needs to be further integrated with facility agronomy. In terms of software, due to the lack of a large amount of experimental data support, most plant factories in China mainly carry out single factor independent regulation by computer program based on empirical parameters or expert system. Its rationality and accuracy need to be further improved (Fang et al., 2021).

EXISTING PROBLEMS

Passive perception of environmental information

The acquisition of growth environment and biological characteristics information is the basis of the digital, intelligent and modern plant factory (Wang et al., 2021). Traditional monitoring and information acquisition mainly rely on the deployment of various sensors or detection equipment in plant factories, which are transmitted through various wired or

wireless buses or protocols, and collected centrally by computers. This method not only increases the initial investment cost of the plant factory, but also makes the communication wiring between systems complex and cumbersome, and the movement of automatic mechanical equipment in the plant factory is greatly restricted (Xu, 2020). In addition, there are many metal material frames in the planting plant of the plant factory, which cause strong electromagnetic interference, poor stability of wireless communication, low transmission rate of monitoring information and frequent information loss (Zhang et al., 2019).

Low positioning accuracy of indoor intelligent mobile equipment

Plant factories have high requirements for air tightness, walls and insulation materials may shield radio waves, and many indoor intelligent mobile devices that rely on global positioning system (GPS) or BeiDou Navigation Satellite System (BDS) and other satellite positioning systems cannot meet precise movement control due to reduced positioning accuracy (Liu & Huang, 2021). At present, indoor positioning mainly uses infrared, ultrasonic, Bluetooth, ultra-wideband, wireless LAN, RRFID and other wireless positioning technologies, but these technologies have electromagnetic interference, low accuracy, complex construction, limited scale, high equipment cost and many other problems (Zhang, 2021; Li et al., 2021; Cao et al., 2020).

Low automation of planting management

In the plant factory, in addition to the planting management of sowing, germination, seedling raising, transplanting, field planting, patrol, replanting, pruning and harvesting, the planting tray, nutrient solution transmission tank, reservoir, filter, pipeline and other equipment need to be cleaned for crop cultivation. At present, these tasks do not realize automatic operation, and the degree of intelligence is also very low, which is mainly completed manually (Liu et al., 2021; Ren et al., 2020). In addition, in order to make full use of space and expand the planting area, the three-dimensional vertical cultivation mode of multi-layer hydroponics is generally adopted, which has heavy planting equipment, high labor intensity and climbing operation, and has great potential safety hazards (Zhang et al., 2019). Moreover, due to the low degree of overall automation, a large number of personnel and equipment are required to enter and leave the cultivation workshop repeatedly, which is easy to bring pathogens and cause environmental pollution (Liu, 2020; Yu & Liu, 2014).

Inaccurate nutrient solution regulation and circulation

Plant growth cannot be separated from adequate nutrients, lack of nutrients will reduce plant yield and quality, and excessive supply will cause huge waste (Shao et al., 2021). In the existing plant factories in China, the preparation of nutrient solutions is mostly based on the experience of experts to determine the mixing ratio of water and fertilizer. After mixing and stirring, it is directly transported to the root of the plant through pipes, and then recycled. The mixing and supplement of nutrients lack scientific experimental data and crop growth model support, and precise regulation has not yet been achieved (Yang et al., 2021; Zhang, 2021; Sun et al., 2018). Moreover, the dissolution and dilution of solid nutrients, the supplement of nutrient solution required for growth, and the control of waste liquid recovery and discharge require a lot of human labor (Guo et al., 2020; Xia, 2020).

DEVELOPMENT SUGGESTIONS

Research and development of information active perception and acquisition system

An agricultural ecological environment detection sensor, an image sensor and the like are installed on the unmanned aerial vehicle mobile device. This was made to construct target self-searching and active mobile unmanned monitoring system equipment, so as to realize full-automatic and all-weather nondestructive inspection of the planting environment and the growth of plants in a plant factory and active perception of comprehensive information. Such a detection system is flexible and intelligent, and has strong adaptability to different crops. They form a network and interconnect through the Internet of things technology without installing communication devices and additional wiring, which reduces system

expense and makes communication more efficient. In addition, multi-sensor fusion technology is used to comprehensively process multi-sensor or multi-source information and data (Yang & Han, 2019), so as to obtain more abundant and operative information, enhance the effectiveness and robustness of the sensor system and avoid the limitations of a single sensor.

Development of unmanned intelligent equipment for indoor high-precision positioning

Indoor high-precision positioning technology is one of the key technologies for intelligent equipment in unmanned plant factories. It is found that the visible light emitted by LED lamps for plant growth illumination can be used not only for plant photosynthesis, but also for fast and high-precision positioning and navigation of intelligent equipment in plant factories (Wei et al., 2021). The dual functions of lighting and positioning can be realized without the installation of extra special positioning and navigation devices, and it also overcomes the difficulties of no satellite positioning signal indoors, high complexity and low positioning accuracy of rf positioning technology, and has the advantages of strong anti-interference and high positioning accuracy.

Research on precise regulation of environmental multi-factors

Each environmental factor of canopy and root zone has different effects on plant growth and development, mainly including temperature and humidity, light, moisture, CO_2 in air, dissolved oxygen in root zone, canopy air circulation, nutrients and minerals, etc. Plants are affected by the comprehensive action of many factors at the same time, and a small change of one factor may cause large changes of other factors, and while acting together on plant growth, it will have a greater impact on plant development. Therefore, it is challenging to not only promote the rapid development of plants but also enhance the comprehensive utilization rate of resources. At present, the precise and coupling regulation of environmental multi-factors has become one of the important contents of research of intelligent plant factories.

Crop growth process model and agricultural expert system are the basis for the intelligent plant factory to realize multi factor coupling and accurate regulation (Xu et al., 2021). The crop growth model can quantitatively describe the dynamic processes of crop growth, development, fruit formation and yield according to meteorological conditions, soil conditions and crop cultivation and management measures.

The agricultural expert system can be applied to various fields of agriculture, such as crop cultivation, plant protection, formula fertilization, agricultural economic benefit analysis, marketing management and so on.

In China, the research on these aspects mainly focuses on four aspects: Multi-source environmental information fusion monitoring (Yang et al., 2021), non-destructive monitoring of plant growth based on computer vision (Liu, 2020), construction of crop growth model based on in-depth learning (Cen et al., 2020), and environmental multi factor coupling and accurate regulation based on crop growth model (Zhu et al., 2020), mainly focusing on the comprehensive intelligent regulation of plant canopy and root zone.

The smart plant factory oriented crop growth model and expert decision-making system, including expert decision-making model library, is mainly used for accurate collaborative management of crop growth, environmental change and intelligent facilities and equipment, prediction of crop growth trend, comprehensive analysis of a variety of real-time monitoring information, and formulation of nutrient solution management, LED light modulation, comprehensive dynamic management decision-making scheme for environmental factor regulation. At the same time, the system also has the functions of agricultural materials management, technical database and personnel management, which helps to improve the planting production efficiency and reduce the management cost.

Automatic precision logistics equipment research and development

A low-cost autonomous mobile seedbed, three-dimensional multi-layer cultivation rack and corresponding logistics control system are designed and developed by comprehensively using sensor, automatic control, model driving, visible light communication and other technologies (Tang, 2017).

The system will automatically transport the mobile seedbed or planting shelves that need irrigation and planting to the designated position of the planting area, and also automatically transport the mobile seedbed or planting shelves that need harvesting or treatment to the operation workshop, so as to facilitate workers to concentrate on efficient operation or other mechanical equipment for automatic processing.

CONCLUSIONS

In recent years, with the rapid development of science and technology and national economy, China's facility agriculture has developed rapidly. Plant factory is an important part of facility agriculture, and its basic scientific research, engineering construction and production management technology development are also improving steadily. The intelligent development of plant factory equipment is promoting the plant factory to become a new industrial form of modern agriculture. In the future, it is possible to build plant factories directly in urban areas as a sustainable form of urban productive agriculture.

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REFERENCES

Cao, Z.T., Guo, Y., Zhao Z.X., & Liu, M.Y. (2020). Indoor positioning technology research review. *Computer technology and development*, (06), 202-206.

Cen, H.Y., Zhu, Y.M., Sun, D.W., & He, Y. (2020). Application status and Prospect of deep learning in plant phenotype research. *Journal of Agricultural Engineering,* (09), 1-16.

China Zhiyan Data Research Center (2021). 2021-2027 China Plant Factory Market Analysis and Development Trend Research Report. Beijing, China: China Institute of Economics and Industry, 156-182. http://www.abaogao.com/b/qita/11438247MM.html

Fang, H., Cheng, R.F., Wu, G., & Liu, Q.X. (2021). The effect of greenhouse multi-layer stereoscopic cultivation combined with supplementary light on the yield and quality of lettuce. *Journal of China Agricultural University,* (07), 147-154.

Guo, X.Y., Xue, X.Y., Lu, J.L., & Sun, S.H. (2020). Research status and prospect of intelligent equipment in plant factories in China. *Chinese Journal of Agricultural Machinery Chemistry*, (09), 162-169.

Kozai, T. (2013). Plant factory in Japan: current situation and perspectives. *Chron Hortic,*53(2), 8-11.

Kozai, T., Niu, G.H., & Takagaki, M. (2015 Eds.). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production* (pp.423). London, Academic Press.

Kozai, T., Niu, G.H., & Takagaki, M. (2019). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production* (Second Edition) (pp.3-5). Academic Press: London, United Kingdom.

Li, G., Yu, X., & Wang H.C. (2021). Simulation of indoor pedestrian positioning method based on WiFi fingerprint filtering method. *Computer simulation,* (04), 366-370.

Liu, H.F., Gao, X., Li, S.Z., & Wen, X.Y. (2021). Design of automatic logistics system in plant factories. *Modern agricultural equipment,* (03), 22-26 + 48.

Liu, T. (2020). Countermeasures for pest control of pollution-free vegetables in solar greenhouse. *Modern agriculture research,* (01), 126-127.

Liu, Z.H., & Huang, J.J. (2021). Multi-source fusion indoor positioning method based on image calibration. *Surveying and mapping geographic information,* (S1), 272-275.

Liu, W.Q. (2020). Using Computer Vision Technology to Realize Non-Destructive Monitoring of Greenhouse Plant Growth. *The Frontiers of Society, Science and Technology,* 2(1), 131-138.

Mitchell, C.A. (2004). Controlled environments in plant-science research and commercial agriculture. *IJOB,* 33, 1-12.

Ren, R.B., Nie, R.X., Chen, X.W., & Zhang, T.Z. (2020). Development status and prospect of intelligent plant factories. *Modern horticulture,* (07), 69-70.

Shao, M.J., Liu, W.K., Zhou, C.B., & Li, B.S. (2021). The effects of duration and frequency of strong light irradiation on the growth and nutrient absorption of lettuce under LED red and blue combined spectrum. Spectroscopy and spectral analysis, (09), 2853-2858.

Sun, M.Y., Song, J., Hu, Q.X., & Yang, S.J. (2018). Key technology development of plant factories. *Agricultural engineering,* (06), 62-66.

Tang, C.S. (2017). Research on the composite process of ADSS model based on model-driven and workflow. doctoral dissertation, Chinese Academy of Agricultural Sciences (pp. 32-56). https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CDFDLAST2018&filename=1017269542.nh.

Wang, N., Jiao, Z.W., Li, D.Y., & Wang, N.P. (2021). Research progress on key technologies of green facility agriculture cultivation in China. *Jiangsu Agricultural Sciences,* (18), 18-24.

Wei, Z.S., Xue, Q., Sun, X.H., & Wang, Z. (2021). High-precision visible light positioning method based on

adaptive filter. *Optical communication technology,* (09), 5-10. doi: 10.13921/j.cnki.issn1002-5561.2021.09.002.

Xia, B. (2020). The intelligent sprinkler irrigation system in plant factories. *Fujian Agricultural Machinery,* (02), 39-41.

Xu, L.H., Zhang, D.S., Li, X., & Wei, R.H. (2021). Construction and validation of second-scale greenhouse tomato crop-environment interaction model. *Journal of Agricultural Engineering,* (08), 212-222.

Xu, D. (2020). Research on double closed-loop optimal control of greenhouse based on online feedback of crop state. Doctoral dissertation, Chinese Academy of Agricultural Sciences. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CDFDLAST2021&filename=1021040879.nh.

Yang, J., Zhang, D.S., Li, X., & She, G.X. (2021). High-efficiency grape-cucumber interplanting cultivation mode under precise control of digital agriculture. *Yangtze vegetable,* (17), 34-35.

Yang, P., Zhao, Y.Y., Li, Y.M., & Li, Z.B. (2021). Summary of agricultural open space integration based on multi-source information fusion. *Journal of agricultural machinery*, (S1), 185-196.

Yang, Q.C. (2019). Plant Factory. *Chapter I, Summary* (pp. 2-5). Beijing: Tsinghua University Press.

Yang, Q.J., & Han, L. (2019). Research on multi-sensor data intelligent fusion method in agricultural Internet of Things. *Modern electronic technology,* (20), 29-32.

Yu, X.S., & Liu, Y.P. (2014). Factors affecting plant quality in plant factories and their control. *Agricultural outlook,* (05), 52-55.

Zhang, C., Chen, X.B., Cao, P.B., & Yang, Z.M. (2019). Based on multi-spectral continuous adjustable plant Internet of Things cultivation system. *Industrial control computer,* (01), 33-35+38.

Zhang, L., Zhou, J.Q., Ju, W.J., & Yang, W.J. (2021). Research and application of ranging system based on ultrasonic and infrared technology. *Electrical automation,* (03), 99-101.

Zhang, M.Q. (2021). Temperature and humidity environment control and experimental study of artificial light source plant factory. PhD thesis, Heilongjiang Bayi Agricultural University .https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CDFDTEMP&filename=1021064369.nh.

Zhang, Z.W., Zhao, X., & Gao, J.L. (2021). Research and implementation of plant factory environment monitoring system based on LoRa and configuration software. *Agricultural equipment technology,* (04), 14-17.

Zhang, C. Huang, X., Liu, L., & Wei, F. (2019). Orbital efficient cultivation and benefit analysis of green leaf vegetables in solar plant factories. *Chinese vegetables,* (09), 89-92.

Zhu, Y., Tang, L., Liu, L.L., & Cao, W.X. (2020). Research progress of crop growth model. *Chinese Agricultural Sciences,* (16), 3235-3256.