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Smart Agriculture and IoT Technology

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Abstract This paper firstly describes the main applications of Internet of Things (IoT) in modern agriculture and achievements made on the basis of these technologies. It introduces the role of IoT in modern agricultural practices such as vertical farming (VF), hydroponics and phenotyping. Then, it analyzes the potential of wireless sensors and IoT in agriculture, and incoming challenges when integrating this technology with traditional agriculture. In addition, it lists the sensors that can be used in specific agricultural applications, and the main current and future agricultural application scenarios and platforms based on IoT. It also reviews the relevant research being carried out by major technology companies at home and abroad. It is intended to help researchers and agricultural engineers to implement the technology based on the IoT and realize the construction of smart parks.

Key words Internet of Things (IoT), Smart agriculture, Modern agricultural practices

1 Introduction

To increase agricultural yields and reduce resource and labor input, humans have been making various innovations throughout the history. China is a large agricultural country. With the development of urbanization, the arable land and the agricultural population will become less and less, and will face the problems of who will farm the land and how to farm. In recent years, the Internet of Things (IOT) has started to affect agricultural production from urban to rural areas. Modern sensors can monitor the crop growth in real time, and can detect early stresses beyond the reach of the vision of human beings in advance[1]. From sowing to harvesting, from storage to transportation, using a series of sensors is not only smart but also has cost benefit. At present, the application of IoT technology is still not deep, and the application ecology is not perfect (Fig. 1). However, from the development of the past 10 years, it can be predicted that with the construction of infrastructure (smart equipment, sensors, communication networks) and the improvement of a series of services, such as data collection, cloud intelligent analysis and decision-making, friendly user interface and agricultural operation automation, the IoT-based smart agriculture will inevitably bring about great changes in the agricultural industry chain[2]. It is true that China's agricultural production is mainly based on the traditional planting model. From the global perspective, today's agriculture is developing towards an intelligent development with the IoT as the link and the data as the center. This challenges the cultivation model that relies on experience and provides China with new opportunities for leaps in agricultural production.

2 Main applications of the IoT

With the implementation of the state-of-the-art sensors and IOT technologies in agricultural production, traditional agriculture can be fundamentally changed in all aspects. At present, the seamless integration of wireless sensors and IOT in smart campuses can elevate agriculture to an unprecedented level[3]. In smart agricultural parks, IoT can help solve and improve many traditional agricultural problems, such as drought response, growth regulation, land suitability, irrigation, and prevention and control of plant diseases and insect pests. Fig. 2 illustrates the main application fields, problems solved, and sensors involved in smart agriculture.

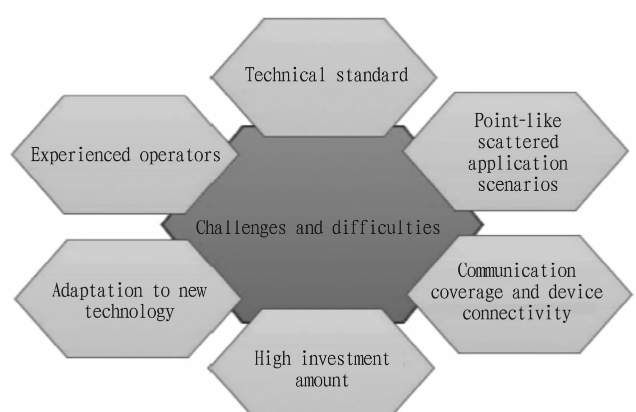

Fig. 1 Main obstacles to the application of smart agricultural technologies

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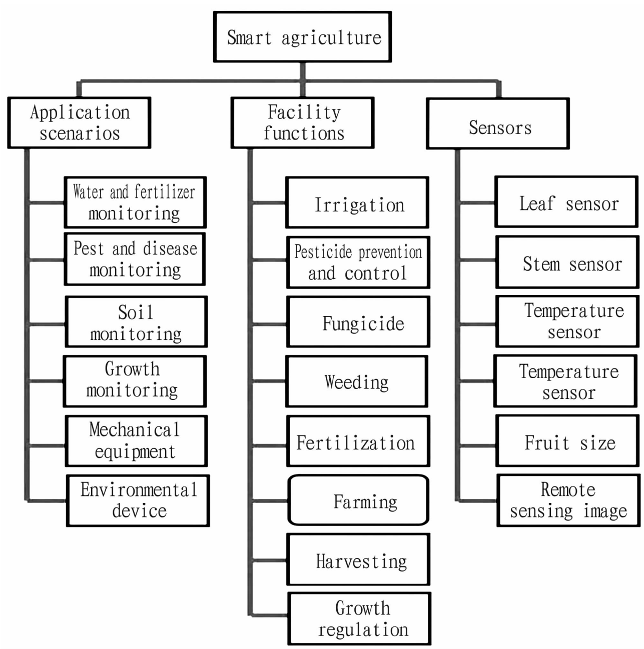

Fig. 2 Application fields of smart agriculture

2.1 Farmland quality monitoring A wide range of inspection kits and sensors provided by many manufacturers can help farmers track soil quality, transfer the knowledge of soil analysis experts and agronomists to farmers in a fast and easy manner, form complete soil analysis reports, and also can customize fertilizer recommendations. In remote rural areas, low-altitude and satellite remote sensing is being used to obtain high-density soil moisture data and analyze drought conditions. The SMOS (Soil Moisture and Ocean Salinity) satellite launched in 2009 and the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite launched in 2010 have had many successful applications in soil water content and surface evapotranspiration calculations.

2.2 Irrigation The extensive operation of flood irrigation not only wastes water resources, but also causes negative effects such as loss of soil nutrients. With the aid of a real-time monitoring system based on wireless sensors, it is able to accurately obtained soil and air moisture content and crop canopy parameters. Combined with remote sensing data, terrain and soil characteristics, and using intelligent analysis software, the crop water stress index (CWSI) can be calculated, and the variable rate irrigation (VRI) of the irrigation system can be controlled to promote the healthy growth of crops[4].

2.3 Fertilization Using the IOT-based fertilization model, it is possible to estimate the spatial distribution of crop nutrient demand with higher accuracy and minimum labor. Using the Normalized Difference Vegetation Index (NDVI) generated from aerial (space) remote sensing data, we can monitor crop nutrient status, health, vegetation vitality and density, and further assess soil nutrient levels. Using variable fertilization patterns, it is feasible to significantly increase the fertilizer efficiency and also minimize adverse effects on the environment[5].

2.4 Prevention and control of crop diseases and insect pests

The reliability of management of crop diseases and insect pests depends on three aspects: perception, decision-making and symptomatic treatment. The state-of-the-art disease and pest identification methods are based on image processing, using unmanned aerial vehicles (UAVs) or remote sensing satellites to obtain raw images of the entire crop area. Besides, field sensors collect data and images from all directions during the crop growth period, such as environmental sampling, plant health status, and automatic trapping and counting of pests, and upload them to the cloud platform for analysis and decision-making through the IoT[6]. Under the guidance of the flight control system, UAVs and intelligent robots can automatically spray pesticides according to a predetermined plan. Engineers are developing an intelligent machine that can autonomously operate according to uploaded disease data and pull out PVY-infected potatoes from the ground[7].

2.5 Crop monitoring and yield estimation Crop monitoring and yield estimation are an important part of smart agriculture. Taking fruit as an example, the same fruit, with different quality and maturity period, corresponds to different markets and consumer groups. Through installing sensors such as fruit, stems, leaves, and insect pests in the orchard, it is able to automatically obtain real-time fruit tree information through the farm LAN. Generally, the fruit size plays a key role in estimating its ripeness, pricing, and determining the market to put it on, and changes in fruit color (RGB) are also often used to judge its ripeness and quality[8]. For staple food crops, aerospace remote sensing is an effective method for monitoring and estimating the yield. Since 2000, China has carried out research on remote sensing monitoring of rice, winter wheat and corn and put it into the business operation[9].

3 Frontier applications of IOT technology

Humans have been adopting various methods to improve the quality and quantity of food. Initially, humans improved crop yields by introducing and breeding good seeds, using chemical fertilizers and pesticides, but now scientists have started to study other alternatives, such as bioengineered foods. However, people prefer traditional green food and organic food. Agronomists hope to increase yield without or less affecting the original properties of crops. In particular, the IoT-based sensor technology is promoting the changes in the production method of traditional agriculture, and controlling the growing environment of crops through sensors to achieve the purpose of green and high yield production. With the acceleration of urbanization, this production method will become increasingly important.

3.1 Greenhouse farming Greenhouse farming is the oldest form of smart farming. In a controlled environment, crops are grown with little environmental impact and are not subject to sunlight during the day. Successful planting depends on a variety of factors, such as the accuracy of monitoring parameters, the structure of the greenhouse, covering materials, ventilation systems, decision support systems, *etc*. Accurate monitoring of environmental parameters is the key task in modern greenhouses, which require multiple parameters and multiple measurement points to ensure the greenhouse microclimate. The greenhouse multi-parameter monitoring platform is mainly composed of four modules (Fig. 3), and the IoT is an important support for the system[10].

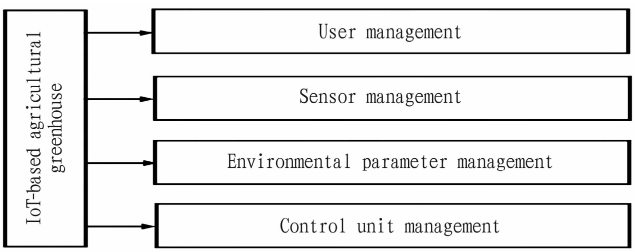

Fig. 3 Modules of greenhouse management system

3.2 Vertical farming Vertical farming (VF) is a solution to the challenges of farmland and water shortages. In the VF, crops are placed vertically in a more environmentally controlled agricultural factory in the form of urban farming, which will significantly reduce resource consumption. Compared with traditional farming, VF requires only a small part of the ground (depending on the number of layers in the stack), and enterprises can multiply production. With its patented agricultural stack technology, Aerofarms has built a complete digitally controlled farm that integrates hardware, automation equipment, intelligent controls and sensor systems to form a powerful data loop. A team of engineers, botanists and programmers collects and analyzes data through 26 annual crop rotations and applies these results to continuous improvement of the farm. Its annual productivity is 390 times that of traditional field farming, while reducing 95% water consumption and achieving zero pesticides.

3.3 Hydroponics Soilless cultivation is a form of hydroponics. It is based on a circulating irrigation system. The nutrients the crop needs are precisely dissolved in the water and the crop roots are soaked in this solution as needed. When combining hydroponics and vertical farm, crop maturity can be shortened by three times due to a controlled environment. A 100 m^2 ground can produce 40 times the yield of a traditional farm. In addition, the use of water and fertilizers can be reduced by 95%, and since there is no soil, there is no need for pesticides and herbicides.

3.4 Plant phenotype Several advanced technologies are being tested in an attempt to increase crop productivity by non-invasively controlling the physiological characteristics of crops through state-of-the-art sensors and IoT technologies. Phenotyping connects plant genomics with ecophysiology and agronomy. Plant phenotype is an assessment of an expression trait (influenced by changes in genetic composition and environment). It is an important process in crop improvement. In the past decade, with the help of molecular and genetic tools, molecular breeding has achieved remarkable results. However, due to the lack of quantitative analysis tools for crop morphology, phenotypic studies have made little contribution to crop breeding. Recent studies[11] have shown that, supported by modern technologies such as the IoT, high-throughput observation facilities, and big data mining, plant phenotypes are very helpful for studying quantitative crop characteristics. Agricultural engineers have developed a variety of automatic control systems to process data generated from observations and measurements. Feature analysis algorithms and machine learning modeling provided by these systems are helpful for exploring the relationship between genotype, phenotype, and growth environment. A number of domestic and foreign companies have developed a variety of advanced plant phenotyping equipment, such as portable crop phenotype imaging analysis system, portable chlorophyll fluorescence measurement and imaging system, portable plant spectrum and hyperspectral imaging measurement system, UAV plant phenotype analysis platform, *etc*. Plant phenotyping combinines remote sensing vegetation index, high and low-throughput measurement, IoT, big data, and visual (LIDAR) 3D modeling, and will be an important new approach to smart agriculture.

4 Development and challenges of smart agriculture IoT

The IoT-based smart agriculture is constantly updated in agricultural planning, production, management and sales, *etc*. Humans are making effort to provide more affordable smart tools for a range of farming activities. To constantly increase the commercial value, it is necessary to achieve good input-output benefits like other industries and benefit farmers. In order to achieve this goal, major Internet companies and high-tech companies both at home and abroad have worked out ambitious plans and continued to promote them (Table 1). From Table 1, it can be seen that the IoT-based smart agriculture is developing rapidly. However, there are obvious limitations and deficiencies in practical applications. Apart from the six aspects indicated in Fig. 2, there are also three technical challenges in IoT.

4.1 Data standards and compatibility Equipment from different manufacturers adopts different standards. Then, hardware, network protocols, application programming interfaces, syntax, semantics and platform will be incompatible. This makes data exchange complex and will hinder the integration between systems.

4.2 Low Power Wide Area Network (LPWAN) technology In remote rural and complex geographic environments, sensors have to withstand harsh environmental conditions while relying on low battery power to remain active and reliable for long periods of time. Therefore, it is necessary to implement low-power communication techniques between a large number of devices over a wide area.

4.3 Security and privacy Protection The entry port is scattered, and a large amount of data is transmitted to the application terminal, which increases the risk of virus infection. All security measures must also take into account the low computing power, small storage space and short battery life of end devices.

Table 1 Status and future prospects of major technology companies in agricultural industry

Company	Current status and vision
Microsoft	AI for Earth: creating key technologies for climate, agriculture, biodiversity and water, and using cloud computing, AI, and IoT to solve agricultural problems. Farmbeats is its main project and it aims to provide farmers with mass production solutions.
Google	Providing cloud-based services for agriculture, as well as various open source technologies such as climate control in a standalone environment. Its Climate Recipes agricultural program proposes solutions for plant phenotypic responses linked to environmental, biological and other genetic variables.
Watson, IBM	Its AI-based services provide an agricultural platform that uses modern technology and IoT to realize smart agriculture, increase the yield, quality of agricultural products and sustainable agricultural development, and provide high-tech resources for a complete ecosystem from farm to fork.
Intel	Infiswift is an IoT platform that improves the efficiency of agricultural operations by linking the entire agricultural industry chain. It builds interconnected big data systems to securely collect, transmit, analyze and process critical data to promote agricultural production.
Baidu	Relying on Baidu Brain to provide digital services to agriculture and agricultural machinery enterprises; using Baidu image technology to provide early warning and detection of pests and diseases; using knowledge map technology to guide agricultural production with expert experience.
Jasper, CISCO	Providing agricultural enterprises with a cloud-based software platform that includes IoT services; using automation, real-time vision and remote diagnostics to realize smart farming.
Dell	Equipped with agricultural robots, agricultural brains and intelligent machines, capable of autonomous learning; cooperating with Aerofarms (VF Factory) to accelerate smart agriculture IoT and big data services.
JD. com	Taking UAV plant protection as the starting point, integrating the logistics, finance, fresh food, big data and other capabilities of JD Group, building a smart agricultural community, and forming a modern, standardized and intelligent "JD Farm" to achieve high-quality agricultural output.
Alibaba	Alibaba Cloud ET Agricultural Brain deeply integrates artificial intelligence and agriculture. It has been applied to pig breeding, apple and melon planting, and has functions such as digital file generation, full life cycle management, intelligent agricultural analysis, and full-link traceability.
Mcfly	A smart agricultural big data service provider focusing on visual spectrum technology, using remote sensing, big data, and artificial intelligence to empower modern agriculture, having developed a series of agricultural information collection equipment and platforms.
XAG	Bringing UAV, robots, autonomous driving, artificial intelligence, IoT and other technologies into agricultural production, building an unmanned intelligent agricultural ecology, and taking agriculture enter the 4.0 generation of automation, precision and efficiency.

5 Conclusions

Based on the smart agricultural technology of the IoT, we analyzed several application capabilities of the smart agricultural IOT. Broadly speaking, smart agriculture also includes e-commerce, food traceability, agricultural leisure tourism, agricultural information services, *etc.*, and smart agriculture will play an increasingly important role. In addition, we also discussed frontier application scenarios of smart agriculture using IOT technology. Although there are many challenges, many foreign and domestic high-tech companies continue to be optimistic about the field of smart agriculture. In the near future, mature applications of the IoT, big data, cloud computing, machine learning, artificial intelligence, and smart equipment will become a reality.

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