Analysis of the frontier technology of agricultural IoT and its predication research

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Abstract. Agricultural IoT (Internet of Things) develops rapidly. Nanotechnology, biotechnology and optoelectronic technology are successfully integrated into the agricultural sensor technology. Big data, cloud computing and artificial intelligence technology have also been successfully used in IoT. This paper carries out the research on integration of agricultural sensor technology, nanotechnology, biotechnology and optoelectronic technology and the application of big data, cloud computing and artificial intelligence technology in agricultural IoT. The advantages and development of the integration of nanotechnology, biotechnology and optoelectronic technology with agricultural sensor technology were discussed. The application of big data, cloud computing and artificial intelligence technology in IoT and their development trend were analysed.

1 Introduction

IoT is the third wave of the development of the world information industry after the computer and the Internet [1]. With the rapid development of nanotechnology, biotechnology and photoelectric technology, it has been widely used in the field of agricultural sensor because of its characteristics of small size, high precision, strong sensitivity and good tolerance. It has become the frontier technology of agricultural IoT. In addition, artificial intelligence, big data, cloud computing and other latest technologies have also been successfully integrated into the agricultural IoT [2-3]. At present, many domestic scholars are committed to the research, development and application of the frontier technology of agricultural IoT, and the application of nanotechnology, biotechnology, optoelectronic technology, artificial intelligence, big data, cloud computing and other frontier technologies in agricultural IoT has achieved gratifying results; and they constantly promote the long-term goal of the modernization and informatization of agriculture and promote the rapid development of agricultural IoT[4]. Because the agricultural IoT information technology changes quickly and it is difficult to predict the development of information technology in the future, this paper analyzes the frontier technology of agricultural IoT and predicts the development of agricultural IoT in the future.
Analysis of the frontier technology of agricultural sensor

2.1 Analysis of the frontier technology of nanosensor
Nanotechnology is a branch in the field of science and technology; it regards the research on the structure of the size less than 100nm, synthesis and characteristics of material and its application as the object\(^\text{[5]}\). The diameter of nanostructure (nanowire, carbon nanotube and nanoparticle) is equivalent to that of the chemical and biological sample molecule found, and it has a larger specific surface area, which is easy for surface modification, therefore it attracts high attention and is applied to biosensors\(^\text{[6]}\). Compared with the traditional sensor, the size of nanosensor is reduced and its precision is improved. It is especially important that the nanometer sensor enriches the sensor theory, promotes the sensor production level and widens the sensor application field greatly from the atomic scale. In addition, the nanosensor also has advantages of large interface, providing a large number of material channels and small resistance and others, which are more conducive to the development direction of miniaturization of the sensor.

At present, nanosensor mainly includes chemical and biological nanosensor, nano gas sensor and other nanosensors (pressure, fiber), etc.\(^\text{[7]}\), the advantages and disadvantages are shown in Table 1. It can be seen from Table 1 that the integration of current nanotechnology with agricultural IoT is mainly focused on chemical biology, gas sensitivity, pressure and fiber, and improves the shortcomings of low sensitivity, poor precision, complex structure and others of the traditional sensor, but it still has shortcomings of narrow range of application and high cost. It is predicted that the nanosensor research will be committed to the broadening of the application scope and reduction of the costs and so on.

Table 1: Comparison of advantages and disadvantages of nanosensors

| Sensor type               | Advantages after compared with traditional sensors                                                                 | Current shortcomings                      |
|---------------------------|-------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Chemical and biological nanosensor | Sensitivity is greatly improved, the time is shortened; high-throughput real-time monitoring and analysis is achieved; its size is small and it is cheap | The application scope is limited and the safety is poor |
| Nano-gas sensor          | Selectivity is enhanced, sensitivity is improved, operating temperature is lowered, mass production can be achieved, it is cheap and the structure design is flexible | High cost and low accuracy                |
| Nano pressure sensor     | High measurement accuracy and sensitivity, small size, light weight, easy installation and maintenance              | Smaller application range                |
| Fiber optic nanosensor   | Small size, short response time, achieved minimal invasive real-time dynamic measurement                           | Expensive, poor accuracy                 |

2.2 Analysis of Frontier Technology of Biosensor
Biotechnology develops rapidly; it mainly includes PCR technology, biochip, single cell gel electrophoresis technology, enzyme-linked immunoassay technology, micronucleus technology and biosensor\(^\text{[8]}\). Biotechnology, marked by DNA recombination technology, has been applied to various research fields because of its sensitivity, small size and precision. The application of biotechnology in the sensor produces a special kind of chemical sensor - biosensor. The working principle of biosensor is to use the interaction between enzymes, antibodies, nucleic acids and other components and the objects to be measured, converts the electronic components detected from the objects to be detected into measurable electronic signals, thereby enhance the sensitivity and accuracy of the sensor, which greatly improves the deficiencies of traditional sensor.
Elecrochemical aptamer \cite{9} is a new generation of biosensor that regards the aptamer as molecular recognition substance and combines with electrochemical signal transduction; it is successfully used in protein detection and early diagnosis of disease. Its aptamer not only has high affinity and high specificity for target molecules but also has advantages of sensitivity, fast speed, simplicity, in vivo detection and low cost. In recent years, biosensors mainly include molecularly imprinted biomimetic sensors, imitating double enzyme thrombin aptamer, DNA-PtNPs tree reticular aptamer sensor, biological pesticide sensors; the advantages and disadvantages are shown in Table 2. It can be seen from Table 2 that current integration of biotechnology with agricultural IoT is mainly focused on molecular imprinted bionic, imitating double enzyme thrombin aptamer, DNA-PtNPs tree reticular aptamer, biological pesticides, etc., which improves the shortcomings of low sensitivity, long detection time, poor precision, complex structure, poor stability and others of the traditional sensor, but it still has shortcomings of narrow range of application, high cost and others. It is predicted that the research of biosensor will be committed to the broadening of application scope, reduction of cost and maintenance.

| Sensor type                        | Advantages after compared with the traditional sensor                                                                 | Current shortcomings                                                                 |
|------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Molecularly imprinted bionic sensor| High sensitivity, strong specificity, fast detection and low cost                                                    | low accuracy, limited application range                                              |
| Imitating double enzyme thrombin aptamer | Good selectivity, reproducibility and stability, simple, sensitive                                                  | Application range is narrow, needing maintenance                                      |
| DNA-PtNPs tree reticular aptamer sensor | High measurement accuracy and sensitivity, small size, light weight, easy installation and maintenance            | Narrower range of application                                                      |
| Biopesticide sensor                | Simple and fast; samples do not require pre-treatment                                                               | Narrower range of application                                                      |

2.3 Analysis of frontier technology of photovoltaic sensor

Because the response of photoelectric sensor is fast, it can achieve advantages of non-contact measurement, high precision and resolution, good reliability, small size, light weight, low power consumption, easy integration and others; such sensors are widely used in agriculture, military, aerospace, communication, detection and industrial automation control and other fields \cite{10}. Now, the development of photovoltaic sensing field is mainly focused on the principle research and application development. With the continuous maturation of optoelectronic technology, the practical development of photovoltaic sensors has become the development hotspot and key of the whole field. At present, the sensors designed by means optoelectronic technology mainly include the following sensors; their advantages and disadvantages are shown in Table 3. It can be seen from Table 3 that the current integration of optoelectronic technology with agricultural IoT is mainly focused on the pressure, rotating blade vertebral height, time grid displacement, Fabry-Perot interference temperature, Hartmann-Shack wavefront, humidity and so on, and improves shortcomings of being susceptible to external influences, complex structure, low sensitivity, poor precision, long reaction time, poor practicality, poor tolerance, easy to wear and others of the traditional sensor; but it still have shortcomings of narrow range of application, high cost, high equipment requirements, complex process and others. It is predicted that the research of photoelectric sensor will focus on increasing the range of application, reducing costs and equipment requirements, simplifying the process and so on.
Table 3: Comparison of advantages and disadvantages of photoelectric sensors

| Sensor type                              | Advantages after compared with the traditional sensor                                                                 | Current shortcomings                                                                 |
|------------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Fiber optical pressure sensor            | Strong resistance to external interference, simple structure suitable for integrated mass production; it can form multi-sensor array or network | Need maintenance, complicated operation                                              |
| Optical rotation blade vertebral height sensor | Short measurement time, accurate data, easy to use, higher practical value                                              | Narrower range of application                                                        |
| Time grid displacement sensor            | It does not rely on electromagnetic conversion, has high sensitivity, small size, low load and low power consumption     | Low precision, need maintenance, easily influenced by external interference           |
| All-optical fiber Fabry-Pérot interferometer high temperature sensor | Small hysteresis, good repeatability, small size, high temperature resolution and high practical value                   | Limited application range, short life                                                |
| Shack-Hartmann wave-front sensor         | Sensitive and accurate, easy calibration, good real-time                                                                | Need segmentation of sub-aperture, complex operation, need maintenance               |
| Linear phase inversion wavefront sensor  | It does not need sub-aperture segmentation, high resolution,                                                             | Iterative computation is large and the consumed time is long                          |
| Photosensitive film humidity sensor      | The structure is simple, easy to measure                                                                                  | Easily affected by the outside world; poor practicality; measurement time is long     |
| Optical fiber humidity sensor            | Compact structure, small size, easy miniaturization of system, suitable for measurement on site                         | Measurement range is limited, easy to be influenced by the environment and accuracy is poor |
| Optical fiber grating type humidity sensor | High accuracy, fast measurement, simultaneous measurement of temperature and humidity, high temperature resistance and corrosion resistance | Higher costs                                                                         |
| Waveguide humidity sensor                | High sensitivity, short response time, wide application prospect, easy to be used in the optoelectronic products        | Complex process, high requirements for equipments, not suitable for mass production  |

3 Analysis and predication of agricultural IoT technology

3.1 Analysis and predication of agricultural big data

Big data refers to a data group that is beyond the capabilities of collection, storing, managing and analyzing of traditional database software tools; its characteristics is the large number, diversification and rapid, and it stores, analyzes, and displays mass data \(^{11}\). "Big data" is another major wave of technology of the information technology industry after the Internet of Things and cloud computing; it has becomethe frontier technology of data mining and intelligent application \(^{12}\). The core technology
of big data is the storage computing, which mainly solves the problems of collection, storage, computing, mining, display and application of mass data. It can be simply summarized into three major aspects: cloud storage, processing and mining of big data. At present, the big data used in agriculture are mainly the agricultural production process management data, agricultural eco-environmental management data, agricultural resource management data, big data of agricultural products and food safety management, big data of agricultural equipment and facility monitoring, big data of agricultural research activities and so on. Lin Lanfen et al. [13] designed the geo-spatial analysis and visualization system for agricultural IoT of spatial-temporal data visualization technology based on the process perception of clustering agricultural products; Xue Huaqi et al. [14] constructed the data sharing system of agricultural IoT; based on the regional simulation and evaluation methods from point to surface, Du Keming et al. [15] developed the integration program of IoT monitoring data with Web GIS spatial data; Wang Jian et al. [16] built the intelligent greenhouse system. The technologies of big data applied in different areas and the achieved functions are shown in Table 4.

### Table 4: Construction and application of big data in agricultural IoT

| Application areas                                      | Adopted technologies              | Achieve functions                                                                 |
|--------------------------------------------------------|-----------------------------------|----------------------------------------------------------------------------------|
| Geo - spatial analysis and visualization system for agricultural IoT | Spatial-temporal data visualization technology | Realize the effect of intuitive temporal and spatial visualization analysis for the circulation process of agricultural products |
| Agricultural IoT data sharing system                   | GIS, big data                     | Achieve storage and management of a variety of environmental data information for different bases |
| Integration analysis program of IoT monitoring data with Web GIS spatial data; | Web GIS technology, big data     | Achieve the regional simulation and evaluation from the point to the surface, data map location display, regional monitoring thematic management |
| Intelligent greenhouse system                         | WIFI technology, big data         | Achieve real-time collection, display, storage sharing of environmental data; analyze and judge the collected data; automatically control the sprinkler motor and heating equipment and remote mobile management |

#### 3.2 Analysis and prediction of agricultural cloud computing technology

Cloud computing [17] refers to the convergence of distributed computing, virtualization, network computing, parallel computing and network storage; it is based on the Internet and integrates computing entities of low cost to form a set of complete system with strong computing capabilities, and uses SaaS, IaaS, PaaS and MSP to provide the powerful computing function for each user terminal. Many domestic scholars carry out in-depth research and apply it to various fields of agriculture.

Liu Haiyan, et al. [18] developed a highly flexible and highly scalable irrigation information management system; Yi Yu [19] designed the greenhouse environmental video monitoring system; Liu Yang et al. [20] established the new agricultural production management system integrating data acquisition, digital transmission, data analysis and processing and NC agricultural machinery; Cui Wenshun et al. [21] proposed the solar greenhouse group IoT service platform design program; Zhang Xiangfei et al. [22] built the agricultural IoT cloud platform based on the Cloud computing framework. Technologies of cloud computing applied in different fields and the achieved functions are shown in Table 5.
Table 5: Construction and application of cloud computing in agricultural IoT

| Application areas                        | Adopted technologies                                                                 | Achieve functions                                                                                                                                 |
|------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Information management system for irrigation district | Google cloud computing service platform (GAE)                                        | Achieve the seamless connection of IoT with cloud computing technology, solve the shortcomings of irrigation information management services     |
| Greenhouse environment video monitoring system | Cloud computing, artificial intelligence, wireless communications, sensors and the Internet | Achieve data storage, management control of the greenhouse group, cloud data analysis and other functions; improve the fine operation level of greenhouse production |
| New agricultural production management system | Internet of Things and cloud computing technology                                    | Accelerate the development of agricultural IoT technology, improve the agricultural information technology integration degree, and promote the standardization of software design and agricultural information |
| Solar greenhouse IoT service platform     | Cloud computing, artificial intelligence, wireless communications, sensors and the Internet | Expand the scale of solar greenhouse management, reduce the construction and operation cost of the IoT system, and improve the big data storage and data analysis capabilities of solar greenhouse IoT |
| Shanghai Agricultural IoT cloud platform | Cloud computing, virtualization technology, Web GIS technology, Web Service technology | Effectively reduce the application threshold of agricultural IoT, improve system utilization ratio, promote interconnection among platform systems, collaboration of business, easy to integrate and share data resources |

3.3 Analysis and prediction of artificial intelligence technology

Artificial intelligence refers to the technology of simulating some thinking process and intelligent behavior of people by means of computers; its research areas mainly include Artificial Neural Networks, simulation, Machine Learning Classification, Support Vector Machine, Principal Component Analysis, Neural Network Computing, Decision Support System, and so on. At present, many domestic scholars carry out in-depth research and applied them to all areas of agriculture. Wang Fa et al. [24] constructed the soil drought prediction model based on Bp neural network; Hou Xiaoli et al. [25] designed the mathematical model of soil moisture prediction for irrigation region under different buried depth conditions by means of the Artificial Neural Network (ANN) theory. Chen Jian et al. [26] proposed a new maize variety identification method by combining near-infrared spectroscopy technology with artificial neural network technology. Xu Yong et al. [27] constructed BP artificial neural network model of topological structure; Cui Rixian et al. [28] designed the aboveground biomass estimation model for obtaining the canopy coverage and color index based on winter wheat canopy image analysis. Zou Huadong et al. [29] established BP neural network identification model by using Matlab; Liu Jingran et al. [30] designed the water demand irrigation forecast model for drip irrigation.
crop under film by means of RBF artificial neural network (ANN). The technologies of artificial intelligence applied in different areas and realized functions are shown in Table 6.

| Application areas                          | Adopted technologies                                      | Achieve functions                                                                 |
|--------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------------------------------|
| Soil drought prediction model              | Bp neural network, embedded technology, IoT technology    | Successfully realize farmland drought monitoring and prediction                   |
| Mathematical model of numerical prediction of soil moisture | Artificial neural network (ANN)                           | Accurately predict the distribution of soil moisture in irrigation region under different buried depth conditions and provide technical support for the application of fine irrigation mode |
| Maize variety identification method        | Near-infrared spectroscopy, artificial neural network      | Rapid and non-destructive identification of maize varieties                        |
| Water quality evaluation model             | Bp artificial neural network                               | More efficient, objective and comprehensive detection of practical water quality  |
| Winter wheat biomass estimation model      | Image analysis technology, Bp neural network technology     | Successfully achieve the non-destructive monitoring of winter wheat growth         |
| Spectral information identification model for rice and weed rice leaves | Artificial neural network, principal composition analysis technology | Achieve the non-destructive identification of rice and weed rice leaves, improve the identification accuracy |
| Drip irrigation crop water demand forecasting model | RBF artificial neural network, intelligent irrigation technology | Achieve the purpose of water efficiency                                           |

4 Conclusion and discussion
With the rapid development of science and technology, China's agricultural IoT is becoming perfect, and the technical reserves are becoming mature. At present, China's agricultural IoT is still in the theoretical design or small-scale pilot phase. This paper conducted the research on the application of frontier technology of agricultural IoT in various fields of agriculture, analysed the application of nanotechnology, biotechnology and optoelectronic technology in agricultural sensor technology, their advantages and disadvantages, and expounds the application of big data, cloud computing and artificial intelligence technology in agricultural IoT. From the above analysis, we can know that nanotechnology, biotechnology and optoelectronic technology have been successfully used in agricultural sensors, and they have advantages of small size, simple structure, simple operation, high precision, high sensitivity and fast response, etc., but they still have shortcomings of limited range of applications, high cost, needing maintenance and others. Even though big data, cloud computing and artificial intelligence technology have been successfully used in greenhouse, water, soil, agricultural production, irrigation, information identification and data detection and other agricultural IoT areas, and have achieved a number of related functions, due to the high cost, lack of standard technology and other factors, the wide range of applications of big data, cloud computing and, artificial intelligence.
From the above analysis, we can know that nanotechnology, biotechnology and optoelectronic technology have been successfully used in agricultural sensors, and they have advantages of small size, simple structure, simple operation, high precision, high sensitivity and fast response, etc., but they still have shortcomings of limited range of applications, high cost, needing maintenance and others. Although big data, cloud computing and artificial intelligence technology have been successfully used in greenhouse, water, soil, agricultural production, irrigation, information identification and data detection and other agricultural IoT areas, and have achieved a number of related functions, due to the high cost, lack of standard technology and other factors, the wide range of applications of big data, cloud computing and, artificial intelligence in the agricultural IoT still have the problems of smaller amount, poor readability, low data updating ratio and others. The research of agricultural IoT should focus on frontier technology development, technology integration and application, etc., to solve current problems in the application of agricultural IoT so as to promote China's modern agriculture to fully go into IoT data sharing and artificial intelligence development phase.

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**References**

[1]. Li Denghua, Li Zhemin, et al. “Latest Development of Internet of Things in Advanced Countries and Its Enlightenment to China”. Jiangsu Agricultural Sciences, 44, pp.1-5,(2016).

[2]. Yi Yu. “Design and Implementation of Modern IoT Monitoring System Based on Cloud Computing”. Network and Information Engineering, 19, pp.75-76,(2016).

[3]. Hu Ming. “Development Trend and Application Prospect of Internet of Things”. Information & Communications, 10, pp.176-177, (2015).

[4]. Tian Hongwu, Zheng Wengang, et al. “Application Status and Developing Trend of Open Field Water-saving Internet of Things Technology”. Journal of Agricultural Engineering, 21, pp.1-12, (2016).

[5]. Tarasov A. “Silicon nanowire field-effect transistors for sensing applications”. Basel, Switzerland: University of Basel, (2012).

[6]. Chen KI, Li BR, Chen YT. “Silicon nanowire field-effect transistorbased biosensors for biomedical diagnosis and cellular recording investigation”. Nano Today, 6, pp. 131-154,(2011).

[7]. Liu Kai, Zou Defu et al. “Research and Application of Nanosensor”. Instrument Technique and Sensor, 1, pp. 10-12,(2008).

[8]. Chen Jiachang, Yang Lin. “Application of Biotechnology in Environmental Monitoring”. Journal of Agricultural Environmental Sciences, 24, pp. 325-329,(2005).

[9]. Zhang Juan. “Application of Several Signal Amplification Biotechnologies in Electrochemical Aptamer Sensors”. Dissertation, (2015).

[10]. Jie Feng. “Application of Optoelectronic Technology in Sensing Measurement”. Science & technology View, 4, pp.39-39, (2013).

[11]. Zhao Chen. “Application of Big Data in Forest Industry”. Forest Engineering, 32, pp.32-35,(2016).

[12]. Sun Zhongfu, Du Keming, et al. “Research and Application Prospect of Big Data in Intelligent Agriculture”. Journal of Agricultural Science and Technology, 16, pp.63-71,(2013).
[13] Lin Lanfen, Yu Penghua, Li Zeyang. “Agricultural Product Circulation IoT Perceptual Data Temporal and Spatial Visualization Technology Based on Clustering”. *Transactions of the Chinese Society of Agricultural Engineering, 31*, pp.228–235, (2015).

[14] Hua Xueqi, Sun Mingjie, et al. “Design and Research on Data Sharing System of Agricultural IoT”. *Agricultural Technique and Equipment, 01*, pp.41-43, 1,(2016).

[15] Du Keming, Chu Jinxiang et al. “Design and Implementation of WebGIS in Agricultural Environmental IoT Monitoring System”. *Transactions of the Chinese Society of Agricultural Engineering, 32*, pp.171-178, (2016).

[16] Wang Jian, Chen Lansheng, et al. “Design of Intelligent Agricultural Facility System in Big Data Background”. *Journal of Chinese Agricultural Mechanization, 37*, pp.180-184, (2016).

[17] Zheng Dan, Jia Fang. “Application Research Based on Cloud Computing of Agricultural IoT”. *Electronic Information, 09*, pp.32, (2015).

[18] Liu Haiyan, Wang Guangqian et al. “Research on Information Management System for Irrigation Area Based on Internet of Things and Cloud Computing”. *Journal of Basic Science and Engineering, 21*, pp.195-202, (2013).

[19] Yi Yu.” Research and Application of Intelligent Platform of Agricultural Greenhouse Based on Internet of Things and Cloud Computing”. *Network & Information Engineering, 20*, pp.70-71, (2016).

[20] Liu Yang, Zhang Gang, et al. “Research and Application of Intelligent Platform of Agricultural Greenhouse Based on Internet of Things and Cloud Computing”. *Application Research of Computers, 30*, pp.3331-3335, (2013).

[21] Cui Wenshun, Zhang Zhiiyi et al. “Sunlight Greenhouse Group IoT Service Platform Based on Cloud Computing”. *Computer Engineering, 41*, pp.294-299,305, (2015).

[22] Zhang Xiangfei, Ding Yongsheng, etc. “Construction and Application of Cloud Platform for Agricultural IoT in Shanghai”. *ACTA AGRICULTURE SHANGHAI, 03*, (2016).

[23] Jia Runliang. “Research on Artificial Intelligence Related Technology for Internet of Things”. *Computer Knowledge and Technology, 12*, pp.194-195, (2016).

[24] Wang Fa, Ai Hong. “Design of Early Warning System for Drought Monitoring in Artificial Intelligence IoT”. *Automation & Instrumentation, 30*, pp.23-26, (2015).

[25] Hou Xiaoli, Feng Yuehua et al. “Application Research on Dynamic Prediction Model of Soil Moisture Based on Artificial Neural Network”. *Water Saving Irrigation, 07*, pp.70-72, (2016).

[26] Chen Jian, Chen Xiao, et al. “Research on Maize Variety Identification Method Based on Near Infrared Spectroscopy and Artificial Neural Network”. *Spectroscopy and Spectral Analysis, 28*, pp.1806-1809, (2008).

[27] Xu Yong, Zhao Jun et al. “Comprehensive Evaluation of Seawater Quality in Dagu River Wetland Based on BP Artificial Neural Network”. *Progress in Fishery Sciences, 36*, pp.31-37, (2015).

[28] Cui Rixing, Liu Yadong et al. “Research on Estimation of Winter Wheat Biomass Based on Visible Spectra and BP Artificial Neural Network”. *Spectroscopy and Spectral Analysis, 96*, pp.2595-2601, (2015).

[29] Zou Huadong, Chen Shuren et al. “Spectroscopic Identification of Weed Rice in Rice Field Based on Artificial Neural Network”. *Journal of Agricultural Mechanization Research, 35*, pp.156-158, (2013).

[30] Liu Jingran, Wu Yan-lei et al. “Analysis of Intelligent Water-Saving Irrigation by Artificial Neural Network”. *Jilin Water Resources, 07*, pp.48-49, (2016).