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REVIEW ARTICLE

International competition situation and research focus on Internet of Things for agricultural equipment

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ABSTRACT

Taking SCI papers related to the Internet of Things for Agricultural Equipment Research as the object, comprehensively using bibliometric methods, the paper content analysis methods and expert consultation, the methods, through analyses of paper output trends, hot research topics, leading countries, key research contents, etc. The development trend, international competition situation, and hotspot directions of the Internet of Things for agricultural equipment were revealed, with a view to providing decision support for optimizing research layout and project management.

Keywords: agricultural equipment; Internet of Things; smart agriculture; sensor; SCI papers

1. Introduction

Agricultural Internet of Things technology is an emerging technology to promote the intelligent development of modern agriculture and has been widely used in every link of agricultural production[1]. Among them, the development of agricultural equipment via the Internet of Things (IoT) and the integration of modern IoT technology and agricultural equipment can realize intelligent management of agricultural equipment, effectively integrate agricultural production management information and data resources, and provide an efficient, intelligent, safe, and convenient operation guarantee for agricultural production[2]. At the beginning of 2018, Datian Rural Cooperative, a Chinese agricultural machinery service enterprise, held a seminar on the Internet of Things solution for agricultural machinery enterprises of the “Internet of Things Enabling Enterprises”, marking that China’s agricultural machinery industry has entered the “Internet of Things era”. In the same year, Jiangxi Province took the lead in putting forward the requirement that the purchase of agricultural equipment with a subsidy of more than 10,000 yuan (such as a combine harvester, wheeled tractor, crawler tractor, pick-up baler, rod spray machine, etc.) must be equipped with IoT positioning monitoring[3]. This paper takes SCI papers on agricultural equipment and the and the Internet of Things as the object to

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analyze the international competition situation and research hotspots in this field, aiming to provide decision-making support for relevant science and technology management departments to timely grasp the development situation and research priorities in this field and optimize the research layout and project management.

2. Research data and methods

Taking research papers in the Clarivate Analytics Science Citation Index (SCI) database as the data source, the paper retrieval method was constructed by using the keywords related to "agricultural machinery", "Internet of Things" and "informatization" and the keywords of Internet of Things technology system, combined with the direction of agriculture-related disciplines, etc. Research papers on agricultural equipment and Internet of Things published from 2010 to 2020 were retrieved. Then, the retrieved papers are used as data sets to analyze the international competition situation and research hotspots. The analysis ideas and framework are shown in **Figure 1**.

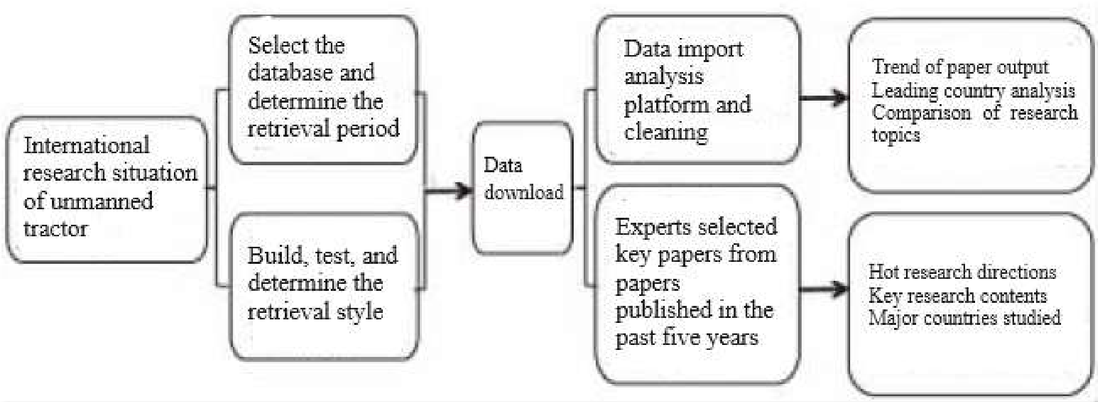

Figure 1. Analysis framework of competition situation and research hots of Internet of Things for agricultural equipment.

The competitive situation analysis takes all retrieved SCI papers as the object and mainly uses the bibliometrics method to analyze. Firstly, the clarivate data analysis tool DDA (Derwent Data Analyzer) was used for data cleaning, including the specification and unification of fields such as country and keywords. Then the tool is used to analyze the cleaned standardized data, including the trend of paper output, comparisons of leading countries, and hot research topics, to reflect the international competitive situation of agricultural equipment IoT.

The research hotspot analysis is based on the retrieved SCI papers with the top 10% of citation frequency in the past five years (2016–2020), mainly using the paper content analysis method. Firstly, the papers published in the past five years were selected from all the above-retrieved SCI papers and selected by experts, and the key papers were interpreted one by one. Then, based on this, the research hotspots and key research contents of the current agricultural equipment on the Internet of Things were analyzed by manual classification according to the research direction.

3. Analysis of international competition situation

From 2010 to 2020, a total of 2764 SCI papers related to agricultural equipment Internet of Things were retrieved, and the annual number of papers showed an increasing trend over time, increasing from 172 in 2010 to 433 in 2019 (with incomplete data in 2020), increasing by more than 1.5 times. Among them, the rapid growth in 2019 reflects that the output scale of research papers on agricultural equipment Internet of Things is in a rising period in recent years, which has attracted more and more attention.

3.1. Leading countries

From 2010 to 2020, the top 10 countries with the largest number of SCI papers are the United States, China, Brazil, Spain, Italy, Germany, Australia, India, Canada and Iran, in order (**Figure 2**). The United States had the largest number of papers, with 771, or about 28% of the total, far ahead of any other country. China was next with 383, or about 14%. Brazil and Spain ranked third and fourth with 303 and 261, respectively. The remaining six countries had around 150 papers or less.

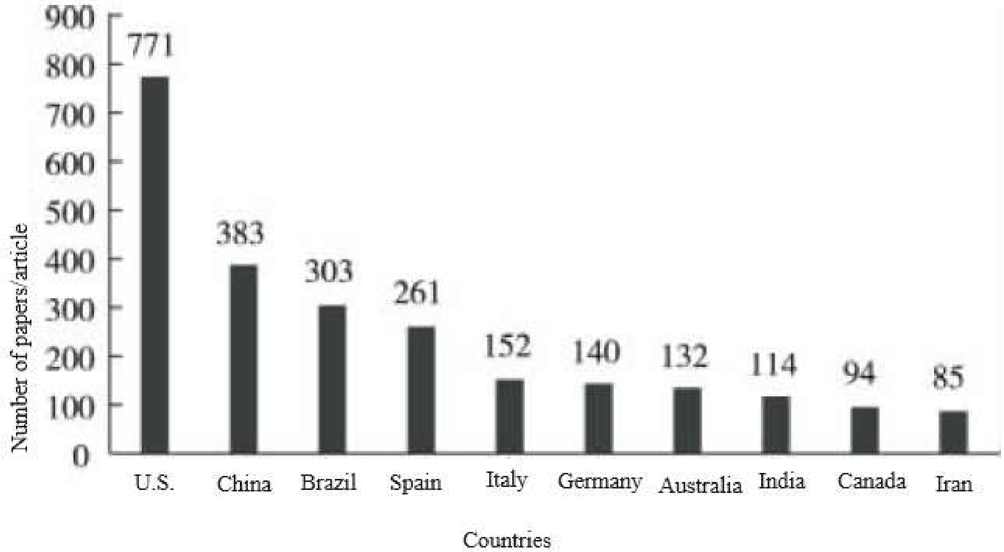

Figure 2. Top 10 countries with the largest number of research papers on Internet of Things for agricultural equipment.

3.2. Hot research topics

The top 10 keywords with the highest frequency and substantial significance in SCI papers from 10 leading countries are extracted to reveal and reflect the hot research topics in the field of agricultural equipment and the and the Internet of Things. The 10 high-frequency keywords were irrigation, sensor, geographic information system, remote sensing, evapotranspiration, soil moisture, normalized vegetation index, maize, machine learning, and artificial neural networks, in order. Then, by analyzing the frequency of high-frequency keywords in the papers of each leading country, the hot research topics that each country focuses on are compared (**Figure 3**). The results show that the United States has a layout in each hot research topic but mainly focuses on irrigation applications and sensor technology; China focuses on remote sensing and sensor technology; Brazil focuses on irrigation applications, normalized vegetation index measurement, and remote sensing techniques; Italy focuses on irrigation applications and GIS; Germany focuses on sensor technology; Australia is mainly concerned with irrigation applications; India and Canada focus on irrigation applications and GIS; and Iran focuses on irrigation applications and artificial neural networks. In addition, maize is the most researched crop in IoT applications and is distributed in all leading countries.

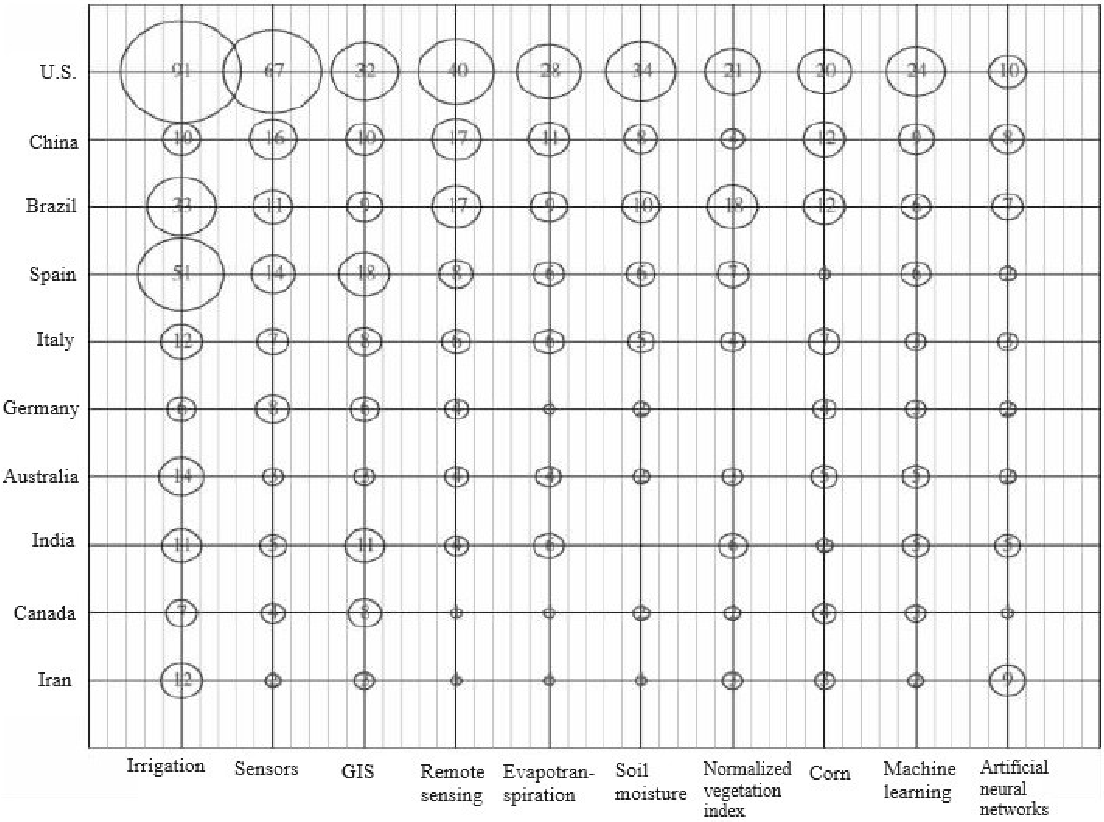

Figure 3. Comparison of hot topics of research papers of Internet of Things for agricultural equipment from top 10 countries. Note: The size of the circle in the figure indicates the frequency of hot topic keywords. The larger the circle is, the higher the frequency is; otherwise, the lower the frequency is. The number in the circle is the frequency of hot topic keywords.

4. Analysis of research hotspots

From the retrieved 2764 SCI papers on agricultural equipment Internet of Things research, 162 papers published in recent 5 years (2016–2020) with the top 10% of cited frequency were selected, and experts were invited to conduct analysis. From a professional perspective, 98 key papers were selected for detailed interpretation and analysis. The research on agricultural equipment IoT mainly focuses on the research and development of perception and control layer technology, application service layer technology, network and network platform layer technology, and environmental impact prediction models. Among them, the number of key papers on sensing and control layer technology is the largest, with 38 articles (2 of which are also research on application service layer technology). The second is the application of service layer technology research, with 33 key papers; then the network and network platform layer technology research, with 17; and the research and development of environmental impact prediction models, with 12 articles.

4.1. Research on sensing and control layer technology

The perception and control layer is responsible for the acquisition of agricultural environment information and animal and plant growth and development by multiple wireless sensors constructed from the terminal, monitoring information through mobile network transmission to the cloud service platform. The information platform of cloud services will obtain data for processing, integration, analysis, and visualization, such as work for environment control, management, etc.[4]. The 38 papers focused on plant physiology and disease information perception (16 articles), job quality monitoring (11 articles), positioning and navigation (7 articles), and animal physiology and behavior information perception (4 articles). In terms of country distribution, they were mainly from China (9 articles), the United States (8 articles), and Spain (4 articles).

Plant physiology and disease information perception are important means to obtain plant growth indicators and detect plant diseases, which is the focus of current agricultural management. At present, Chinese researchers have conducted more studies on crop nutrient detection, for example, the detection of malondialdehyde content in rape leaves based on near-infrared spectroscopy technology and the detection of nutritional information in facility crops based on reflection spectral images[5,6]. Many studies have also been carried out on disease detection technologies and methods[7–9]. In this study, the plant physiological ecology and disease information perception were examined in a total of 16 papers, mainly carried out for corn height, olive tree canopy, metabolism of lettuce growth, pod quantity, cotton seed germination rate, barley grain yield and protein content, moisture content of tea, butterfly orchid leaf growth, and rice disease detection research. The main technologies used are sensor technology (such as acoustic sensors, active optical sensors, lidar sensors, infrared sensors, and active optical sensors) and satellite image technology (**Table 1**).

The quality monitoring mainly monitors the response of maize variety yield and biomass to climate change under sufficient and deficient irrigation conditions, the response of maize hybridization to nitrogen fertilizer, the screening loss of rice in combine harvesters, the influence of the set point of a new intelligent irrigation system on plant physiological response and crop growth, the quality of pesticide spraying and deposition in unmanned aerial vehicle space, the use of chlorophyll meters, the physiological response of spinach biomass yield to the interaction stress of salt and water, the water status of wheat and grain yield under different irrigation methods, etc. (**Table 2**).

The research of positioning technology mainly involves the use of fuzzy spatial decision tools, automatic navigation tractors with laser rangefinders in orchards and plantations, detection of curved and straight crop rows by accumulating green pixels in images of corn fields, route planning of self-driving motorcades applying herbicides at fixed points, application of a three-dimensional stereo vision monitoring system, low-cost positioning and navigation data fusion algorithms of vineyard spray robots, and agricultural machinery design schemes for automatic terrain estimation and classification tasks at the same time, etc. (**Table 3**).

In terms of animal physiology and behavioral information perception, with the development of new technology, Chinese researchers have carried out studies on pig body ruler detection based on depth image, sow delivery detection based on machine vision, and cow breath detection based on video analysis[10–12]. And in this study, animal physiology and behavior of information awareness, a total of four key papers, the main research contents are built using variables such as the nutrients intake and predict methane emissions within the mountain sheep intestines statistical model based on nuclear magnetic resonance (NMR) spectroscopy for fish metabonomics evaluation, using image motion feature extraction to identify pigs aggressive behavior, and the development of an open source algorithm based on smartphone inertial measurement unit Oxgrass intake and rumination behavior were tested (**Table 4**).

Table 1. Research focus of papers in research direction of plant physiological and ecological information perception.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Use of corn height measured with an acoustic sensor improves yield estimation with ground based active optical sensors (2016/27)	North Carolina State University (USA)
2	High throughput phenotyping of cotton plant height using depth images under field conditions (2016/39)	University of Georgia (USA)
3	Mobile terrestrial laser scanner applications in precision fruticulture/horticulture and tools to extract information from canopy point clouds (2017/33)	University of Lerida (Spain)
4	A novel machine Learning method estimating biomass of grass swards using a photogrammetric canopy height model, images and vegetation indices captured by a drone (2018/34)	Finnish Geospatial Research Institute (Finland)

Table 1. (*Continued*).

Serial No.	English title (year of publication/citations)	Affiliation (country)
5	Effect of glycine nitrogen on lettuce growth under soilless culture: a metabolomics approach to identify the main changes occurred in plant primary and secondary metabolism (2018/16)	Shanghai Jiaotong University (China)
6	Intercomparison of surface energy fluxes, soil moisture, and evapotranspiration from eddy covariance, large-aperture scintillometer, and modeling across three ecosystems in a semiarid climate (2018/16)	Virginia Tech & State University (USA)
7	A practical method using a network of fixed infrared sensors for estimating crop canopy conductance and evaporation rate (2018/16)	Dundee University (UK)
8	Seed-per-pod estimation for plant breeding using deep learning (2018/14)	National Council for Scientific and Technological Research (Argentina)
9	Water balance in paired watersheds with eucalyptus and degraded grassland in Pampa biome (2017/14)	Federal University of Santa Maria (Brazil)
10	Monitoring cotton (*Gossypium hirsutum* L.) germination using ultrahigh -resolution UAS images (2018/19)	Texas A & M University (USA)
11	Modeling the seed yield of Ajowan (*Trachyspermum ammi* L.) using artificial neural network and multiple linear regression models (2018/18)	Tehran University (Iran)
12	Mid-season prediction of grain yield and protein content of spring barley cultivars using high-throughput spectral sensing (2017/18)	Technical University of Munich (Germany)
13	Comparison of satellite imagery and ground-based active optical sensors as yield predictors in sugar beet, spring wheat, corn, and sunflower (2017/18)	North Dakota State University (USA)
14	Detecting bakanae disease in rice seedlings by machine vision (2016/18)	National Taiwan University (China)
15	Visualizing distribution of moisture content in tea leaves using optimization algorithms and NIR hyperspectral imaging (2019/17)	Jiangsu University (China)
16	On precisely relating the growth of Phalaenopsis leaves to greenhouse environmental factors by using an IoT-based monitoring system (2017/19)	Taiwan Province University (China)

Table 2. Research focus of papers in research direction of operation quality monitoring.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Modeling yield and biomass responses of maize cultivars to climate change under full and deficit irrigation (2017/17)	Agricultural Research Service, USDA (USA)
2	Corn era hybrid response to nitrogen fertilization (2016/17)	Iowa State Big Virtual (USA)
3	Sensor for monitoring rice grain sieve losses in combine harvesters (2016/16)	Jiangsu University (China)
4	Estimating cotton water consumption using a time series of Sentinel^{-2} imagery (2018/15)	Agricultural research organizations (listed by color)
5	Sensor-based irrigation management of soilless basil using a new smart irrigation system: effects of set-point on plant physiological responses and crop performance (2018/15)	National Research Council (Italy)
6	Testing method and distribution characteristics of spatial pesticide spraying deposition quality balance for unmanned aerial vehicle (2018/15)	China Agricultural University (China)
7	Derivation of sufficiency values of a chlorophyll meter to estimate cucumber nitrogen status and yield (2017/15)	University of Amelia (Spain)
8	Spinach biomass yield and physiological response to interactive salinity and water stress (2017/14)	Agricultural Research Service, USDA (USA)
9	Thermal imaging and passive reflectance sensing to estimate the water status and grain yield of wheat under different irrigation regimes (2017/14)	Sadat City University (Egypt)
10	Sensing - cloud: leveraging the benefits for agricultural applications (2017/14)	Indian Institute of Technology (India)
11	Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying (2017/21)	South China Agricultural University (China)

Table 3. Research focus of papers in research direction of positioning and navigation technology.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Fuzzy spatial decision tool to rank suitable sites for allocation of bioenergy plants based on crop residue (2017/15)	Santander University of Technology (Colombia)
2	Navigation of autonomous tractor for orchards and plantations using a laser range finder: automatic control of trailer position with tractor (2016/15)	Tsukuba University (Japan)
3	Curved and straight crop row detection by accumulation of green pixels from images in maize fields (2018/14)	Comptons University of Madrid (Spain)
4	Route planning for agricultural tasks: a general approach for fleets of autonomous vehicles in site-specific herbicide applications (2016/20)	National Research Council of Spain (Spain)
5	Evaluation of a lidar-based 3D-stereoscopic vision system for crop monitoring applications (2016/18)	Bolzano Free University (Italy)
6	A novel data fusion algorithm for low-cost localisation and navigation of autonomous vineyard sprayer robots (2016/18)	Ben Gurion University (Israel)
7	Terrain assessment for precision agriculture using vehicle dynamic modelling (2017/17)	University of Saranto (Italy)

Table 4. Research focus of papers in research direction of animal physiological and behavioral information perception.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Development of statistical models for prediction of enteric methane emission from goats using nutrient composition and intake variables (2016/17)	West Bengal University of animal and Fishery Sciences (India)
2	NMR-based metabolomics study of the effects of taurine on the metabolism of Nile tilapia (2018/16)	Xiamen University (China)
3	Image Motion Feature Extraction for Identifying Aggressive Behaviors of Group Housed Pigs (2017/16)	Jiangsu University (China)
4	Development of an open-source algorithm based on a smartphone inertial measurement unit (IMU) to detect grazing and rumination behavior of cattle (2017/15)	University of Liege (Belgium)

4.2. Network layer and platform layer technology research

The network layer is an information processing system located in the second layer of the three-layer structure of the Internet of Things. Its function is “transmission”, that is, information transmission through the communication network, including the network layer and the network platform layer. Network layer technologies include end-cloud communication technology, end-end communication technology, network interface technology (between people, machines, and systems), network standard technology (between people, machines, and systems), and collaborative operation technology (algorithms, machine learning, deep learning, etc.). Network platform technology mainly includes agricultural big data collection technology, agricultural big data mining and analysis technology (cross-media data, multivariate data, feature extraction, pattern recognition, cloud computing), and agricultural big data decision technology (expert systems, knowledge systems). In this study, there are 17 key papers on the research direction of network layer and platform layer technology, mainly from the United States (5 articles) and India (2 articles). Among them, six articles study network layer technology, focusing on the development of algorithms based on neural networks and support vector machines in collaborative operation technology (**Table 5**). The 11 articles related to network platform technology mainly studied big data analysis and decision technology (**Table 6**).

Table 5. Research focus of papers in research direction of network layer technology.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Classification of pepper seeds using machine vision based on neural network (2016/17)	Uludag University (Turkey)
2	Artificial neural networks and multiple linear regression as potential methods for modeling seed yield of safflower (*Carthamus tinctorius* L.) (2019/16)	Iranian Agricultural Research, Education and Extension Organization (AREEO) (Iran)
3	Prioritizing climate-smart agricultural land use options at a regional scale (2017/16)	International Maize and Wheat Improvement Centre (India)
4	A comparison of support vector machines, artificial neural network and classification tree for identifying soil texture classes in southwest China (2018/23)	Southeast University (China)
5	Soil moisture sensor calibration, actual evapotranspiration, and crop coefficients for drip irrigated greenhouse Chile peppers (2017/23)	New Mexico State University (USA)
6	Comparison of irrigation automation algorithms for drip-irrigated apple trees (2016/23)	Washington State University (USA)

Table 6. Research focus of papers in research direction of network platform layer technology.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Projecting corn and soybeans yields under climate change in a Corn Belt watershed 2017/16)	Southern Illinois University (USA)
2	AgroDSS: a decision support system for agriculture and farming (2019/15)	University of Ljubljana (Slovenia)
3	Prioritizing climate-smart livestock technologies in rural Tanzania: a minimum data approach (2017/15)	International Center for Tropical Agricultural Research (Kenya)
4	Differential impacts of rainfall and irrigation on agricultural production in Nigeria: any lessons for climate-smart agriculture? (2016/15)	University of ibadan (Nigeria)
5	Partitioning evapotranspiration of a drip-irrigated wheat crop: intercomparing eddy covariance-, sap flow-, lysimeter-and FAO-based methods (2019/14)	University of Kadiyad (Morocco)
6	Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt (2018/14)	North Dakota State University (USA)
7	References evapotranspiration estimation and modeling of the Punjab Northern India using deep learning (2019/22)	Thar Institute of Engineering and Technology (India)
8	Climate and management factors influence soybean yield potential in a subtropical environment (2016/20)	Santa Maria Federal University (Brazil)
9	Evapotranspiration evaluation models based on machine learning algorithms a comparative study (2019/19)	University of Casino-Lazio South (Italy)
10	Long-term impact of a precision agriculture system on grain crop production (2017/17)	University of Missouri (USA)
11	A new portable application for automatic segmentation of plants in agriculture (2017/19)	University of Murcia (Spain)

4.3. Research on application service layer technology

The Internet of Things collects data through the perception layer and transmits it to the application layer through the network layer. The main work of the application layer is to process this data for application development calculation and make feedback according to the data[4]. In this study, there are 33 key papers related to the application of service layer technology, mainly focusing on intelligent irrigation (21 articles), intelligent plant protection (6 articles), intelligent breeding (4 articles) and intelligent fertilization (2 articles) in turn (**Table 7**). In terms of country distribution, they were mainly from Spain (10 articles), the United States (5 articles) and China (3 articles). Smart irrigation uses multi-sensor technology, blade water pressure sensors, cloud servers, machine learning, wireless transmission systems, as well as unmanned aerial vehicles and spectroscopy.

Table 7. Research focus of papers in research direction of application service layer technology.

Application	English title (year of publication/citations)	Affiliation (country)
Intelligent irrigation (21 articles)	Assessing a crop water stress index derived from aerial thermal imaging and infrared thermometry in super-high density olive orchards (2017/33)	University of Seville (Spain)
	Modelling and mapping the economic value of supplemental irrigation in a humid climate (2016/28)	Cranfield University (UK)
	Scheduling regulated deficit irrigation in a hedgerow olive orchard from leaf turgor pressure related measurements (2016/28)	Spanish National Research Council (Spain)
	Applying machine learning on sensor data for irrigation recommendations: revealing the agronomist's tacit knowledge (2018/25)	Ben Gurion University (Israel)
	A software architecture based on FIWARE cloud for precision agriculture (2017/25)	National Distance Education University of Spain (Spain)
	An IoT based smart irrigation management system using machine learning and open source technologies (2018/36)	Indian Council for scientific and Industrial Research (India)
	A decision support system for managing irrigation in agriculture (2016/58)	Polytechnic University of Cartagena (Spain)
	Effects of saline reclaimed waters and deficit irrigation on citrus physiology assessed by UAV remote sensing (2017/27)	National Research Council of Spain (Spain)
	Vineyard water status estimation using multispectral imagery from an UAV platform and machine learning algorithms for irrigation scheduling management (2018/40)	University of Melbourne (Australia)
	Irrigation water management in arid regions of Middle East: assessing spatio-temporal variation of actual evapotranspiration through remote sensing techniques and meteorological data (2019/16)	University of Alberta (Canada)
	Development of an irrigation scheduling software based on model predicted crop water stress (2017/14)	Mcgill University (Canada)
	The Bushland weighing lysimeters: a quarter century of crop et investigations to advance sustainable irrigation (2016/23)	USDA Agricultural Research Service (USA)
	Scheduling irrigation using an approach based on the van-Genuchten model (2016/22)	University of Georgia (USA)/University of Idaho (USA)
	Optimizing drip irrigation for eggplant crops in semi-arid zones using evolving thresholds (2016/20)	Federal Polytechnic University of Lausanne (Switzerland)
	A Wireless Sensor Network (WSN) application for irrigation facilities management based on Information and Communication Technologies(ICTs) (2017/19)	University of Minnesota (USA)
	Soil water content monitoring for irrigation management: a geostatistical analysis (2017/19)	University of Nebraska at Lincoln (USA)
	IoT based low cost and intelligent module for smart irrigation system (2019/18)	Vesco National Institute of Technology (India)
	Use of a smart irrigation system to study the effects of irrigation management on the agronomic and physiological responses of tomato plants grown under different temperatures regimes (2017/18)	National Research Council (Spain)
	A cost-effective canopy temperature measurement system for precision agriculture: a case study on sugar beet (2017/18)	University of Seville (Spain)
	Partitioning of net radiation and evapotranspiration over a superintensive drip-irrigated olive orchard (2016/18)	University of Tarca (Chile)
	Linking thermal imaging and soil remote sensing to enhance irrigation management of sugar beet (2018/19)	University of Seville (Spain)

Table 7. (*Continued*).

Application	English title (year of publication/citations)	Affiliation (country)
Intelligent plant protection (6 articles)	Autonomous systems for precise spraying : evaluation of a robotized patch sprayer (2016/30)	National Research Council of Spain (Spain)
	Development and evaluation of a low-cost and smart technology for precision weed management utilizing artificial intelligence (2019/27)	University of Florida (USA)
	Object-based early monitoring of a grass weed in a grass crop using high resolution UAV imagery (2016/29)	National Research Council of Spain (Spain)
	Develop an unmanned aerial vehicle based automatic aerial spraying system (2016/58)	South China Agricultural University (China)
	An adaptive approach for UAV-based pesticide spraying in dynamic environments (2017/34)	University of Parana Norte (Brazil)
	Real-time variable-rate herbicide application for weed control in carrots (2016/16)	Leibniz Institute of Agricultural Engineering (Germany)
Intelligent breeding (4 articles)	System specification and validation of a noseband pressure sensor for measurement of ruminating and eating behavior in stable-fed cows (2017/32)	Institute for sustainable science in agriculture (Switzerland)
	Categorising sheep activity using a tri-axial accelerometer (2018/27)	University of New England (Australia)
	Development of a threshold-based classifier for real-time recognition of cow feeding and standing behavioural activities from accelerometer data (2017/27)	University of Catania (Italy)
	Image motion feature extraction for recognition of aggressive behaviors among group-housed pigs (2017/16)	Jiangsu University (China)
Intelligent fertilization (2 articles)	Methodology of fertilizer recommendation based on yield response and agronomic efficiency for rice in China (2017/22)	Chinese Academy of Agricultural Sciences (China)
	Variable rate nitrogen fertilizer response in wheat using remote sensing (2016/19)	Michigan State University (USA)

In the field of intelligent plant protection, an automatic spraying and weeding robot is built on a commercial agricultural robot chassis and spraying system. At the same time, it is equipped with on-board sensors and a GNSS (Global Navigation Satellite System) positioning system to monitor weeds; machine vision and artificial intelligence are used to monitor the target. Identify, design, and develop a pepper field weeding and spraying robot; at the same time, connect RTK GPS (real-time dynamic global positioning system) to the intelligent sprayer; develop algorithms to automatically generate weed maps; and use UAV technology to plan the target object's trajectory. Navigation spraying: a computer-based autonomous drone control system is proposed that can precisely change the flight path of the drone for precise pesticide spraying.

In the field of intelligent breeding: Based on the nose strap pressure sensor, online data analysis recorder, and software, a new automatic scientific monitoring device for measuring the rumination and feeding behavior of dairy cows was developed. Based on Bluetooth wireless transmission technology and acceleration sensors, various basic sheep were monitored. behaviors, including grazing, standing, and walking; a new method for distinguishing cow behavior based on accelerometer sensors is proposed, which enables real-time detection of cow feeding and standing.

Intelligent fertilization field: Establish a rice nutrition expert decision support system based on yield response and agronomic efficiency and recommend rice fertilization methods; use remote sensing technology to detect the impact of nitrogen fertilizer on crops; and calculate the spatial response of crops to nitrogen application.

4.4. Research on environmental impact prediction model

There are 12 research papers in the research direction of the environmental impact prediction model. The research focus is to develop various algorithms and prediction models to evaluate or predict the agricultural production environment and its impact on crops based on the relevant monitored data. The evaluation content mainly includes agricultural hydrological processes and irrigation water conservation, the impact of shelterbelts on crop yield, the impact of water vulnerability on rainfed crops, the impact of abiotic stress (drought, cold, iron toxicity, salinity) on rice growth, and greenhouse The relationship between the environment and crop growth, the spatial relationship between soil conductivity and crop yield and soil properties, the effect of nitrogen nutrition on maize, farmland water evaporation and crop transpiration, the spatiotemporal distribution of organic phosphorus, spatiotemporal changes in surface temperature and soil temperature, and The images were evaluated for work environment, etc. (**Table 8**).

Table 8. Research focus of papers in research direction of environmental information perception.

Serial No.	English title (year of publication/citations)	Affiliation (country)
1	Modeling and assessing agro-hydrological processes and irrigation water saving in the middle Heihe River basin (2019/16)	China Agricultural University (China)
2	Development of an in-season estimate of yield potential utilizing optical crop sensors and soil moisture data for winter wheat (2016/16)	Oklahoma State University (USA)
3	Assessment of the effects of shelterbelts on crop yields at the regional scale in Northeast China (2016/16)	Chinese Academy of Sciences (China)
4	Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios (2018/15)	Mohammed bin Abdullah University (Morocco)
5	Mapping abiotic stresses for rice in Africa: Drought, cold, iron toxicity, salinity and sodicity (2018/15)	African Rice Center (Cô te d 'Ivoire)
6	Performance of the two-source energy budget (TSEB) model for the monitoring of evapotranspiration over irrigated annual crops in North Africa (2017/15)	University of Kadiyad (Morocco)
7	A Public-Industry Partnership for Enhancing Corn Nitrogen Research and Datasets: Project Description, Methodology, and Outcomes (2017/14)	Agricultural Research Service, USDA (USA)
8	Spatial Relation of Apparent Soil Electrical Conductivity with Crop Yields and Soil Properties at Different Topographic Positions in a Small Agricultural Watershed (2016/14)	Southern Illinois University (USA)
9	Temporal and spatial changes in soil available phosphorus in China(1990—2012) (2016/14)	Chinese Academy of Agricultural Sciences (China)
10	On precisely relating the growth of Phalaenopsis leaves to greenhouse environmental factors by using an IoT -based monitoring system (2017/19)	Taiwan Province University (China)
11	Automatic detection of curved and straight crop rows from images in maize fields (2017/19)	Complutense University of Madrid (Spain)
12	Using distributed temperature sensing to monitor field scale dynamics of ground surface temperature and related substrate heat flux (2016/18)	University of Wageningen (Netherlands)

5. Outlook

(1) Comprehensive perception is an important foundation for agricultural equipment on the Internet of Things. The IoT of agricultural equipment needs to connect a large number of objects to the network and carry out communication activities, so the comprehensive perception of objects is very important. The perception layer is the basis for the Internet of Things to obtain information. Sensors, radio frequency identification

technology (RFID), global satellite positioning system (GS), global positioning system (GPS), bar code technology, and other sensing devices are responsible for collecting all kinds of information in the physical world. In the future, the rise of 5G communication technology and the completion of the Beidou satellite system will bring new opportunities for agricultural equipment IoT communication.

(2) Information processing is the core of IoT development in agricultural equipment. Through cloud computing, expert systems, artificial intelligence, and other information processing platforms, we finally realize the deep integration of information technology and industry and complete the collection, collaboration, sharing, interworking, analysis, prediction, and decision-making of goods and other functions. With the continuous development of computer technology, more optimization algorithms, machine learning, and deep learning will be applied to agricultural equipment on the on the Internet of Things.

(3) Prediction and decision modeling are difficult points in the research of agricultural equipment on the on the Internet of Things. At present, there are few agricultural prediction and decision models for large-scale applications, mainly due to a lack of data, platforms, software, and so on. Therefore, agricultural information technology is still in its primary stage, and it cannot do real-time diagnosis and processing. In the future, on the basis of strengthening data acquisition and transmission, it is necessary to focus on basic theoretical research such as predictive decision-making models, improve comprehensive data processing and decision-making abilities, so as to strengthen computing services and information control, and promote the large-scale application of agricultural equipment on the on the Internet of Things.

(4) Multidisciplinary integration is an important way for the development of agricultural equipment on the on the Internet of Things. Agricultural IoT technology not only needs knowledge of electronic information but also needs more agricultural knowledge of biological systems, including animals and plants, soil, and environments such as objects, only on the basis of fully understanding the object properties according to the needs of the object and characteristics of structures. Therefore, technologies related to agricultural biosystems will play an increasingly important role in the future development of agriculture. At the same time, specific application layers such as field planting, facility gardening, livestock and poultry breeding, aquaculture, and agricultural logistics not only use the Internet of Things communication technology but also need big data, agriculture, environment, control, and so on. In addition, in order to carry out scientific research on the complex problems generated by agricultural equipment IoT technology, it is necessary to understand the knowledge of other fields and have a comprehensive and multi-domain cognition of the research problems, so as to solve the core problems of agricultural IoT in a real sense. Continuous integration of disciplines and joint discussion of agricultural equipment on the on the Internet of Things is the key to achieving technological breakthroughs.

(5) Intelligent field management is an important direction for the development of agricultural equipment on the on the Internet of Things. Field management is mainly oriented toward plant protection, followed by irrigation and the acquisition of field physiological parameters. Plant protection is the most mature field of agricultural IoT application at present. No matter if it is an automatic spraying device based on a UAV or robot, there are related studies. Most of the detection sensors, data transmission systems, and positioning systems currently applied are mature commercial sensor modules. Application research has focused on path planning and identification of plants, weeds, or pests. At the same time, the research on soil itself is also worthy of attention, especially the soil moisture content detection. At present, the soil moisture content detection carried out in China is mostly offline, and there is no reliable online monitoring sensor for field soil moisture content, which can be regarded as the bottleneck technology or advanced technology and needs to be prioritized for layout research.

(6) Smart pasture will be an important position for future research on the Internet of Things for agricultural

equipment. At present, the development of smart ranches is obviously behind that of smart farms. No matter the technical means applied or the monitoring and analysis of objects, the research on smart farms is not as in-depth as that on smart farms. The possible reason is that the differences and uncertainties of animal physiological and behavioral parameters make it difficult to find rules that can be followed in short-term or small-scale studies. More sample data is needed for effective analysis, and the limitations of farm scale and area limit the application and promotion of IoT technology on ranches. However, agricultural IoT technology based on machine vision has started to be applied in the aquaculture industry, and intelligent farming will see greater development in the future.

Conflict of interest

The authors declare no conflict of interest.

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