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Intelligent Agriculture and Its Key Technologies Based on Internet of Things Architecture

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ABSTRACT In order to promote the efficient development of agriculture, the Internet of Things technology is applied to modern agricultural production, and a smart agricultural system is constructed in this paper. Moreover, the data visualization analysis and cluster analysis are used to find the key technologies in the development of the intelligent agriculture, which can effectively improve the production efficiency and ensure the quality of the agricultural products. Intellectualized products are gradually integrated into agricultural production, and the development of the Internet of Things also gives technical impetus to intelligent agriculture. Through the functions of sensing, identification, transmission, monitoring, and feedback of the Internet of Things, related agricultural activities can be accurately completed, which not only saves the time cost of farmers but also improves the crop yields and, ultimately, benefits the farmers. Therefore, the Internet of Things is used for agriculture induction, identification, monitoring, and feedback, and it is also applied to find the key technology in the application process to achieve intelligent, scientific, and efficient agriculture. It also has certain reference significance for the research of the front-end induction recognition and the intelligence of the Internet of Things in the aquaculture industry.

INDEX TERMS Intelligent agriculture, Internet of Things technology, data visualization analysis, cluster analysis.

I. INTRODUCTION

Since ancient times, China has been a big agricultural country, yet with weak productivity. In addition, China's agriculture is faced with small scale of agricultural production, scattered cultivated land, poor quality of good cultivated land, backward production tools, and rising production service price [1]. As a result, farmers can only engage in simple reproduction activities. Agriculture is the basic industry of the national economy, and agricultural products are the most essential material basis for human survival and development, both of which relate to the livelihood of the country. Therefore, they are very important for farmers, enterprises and even the country. China has very little arable land per capita [2]. How to improve the grain yield per unit area of arable land has become a key issue facing the agriculture at present. At the same time, with the rapid growth of China's national economy, the impact of the reduction of arable land and environmental degradation on agriculture is gradually increasing [3], [4]. In addition, the backward agricultural production technology and the lack of scientific management lead to prominent agricultural problems and low production efficiency in China.

In order to promote the process of agricultural modernization, China has issued a series of policies to support agricultural development and to strive to develop agriculture [5]. With the vigorous development of modern society, intelligent products gradually enter people's life, penetrate into every detail of life, promote the development of life towards science and technology, and further change way of life and improve the quality of life. In the era of rapid development of the Internet, intelligent agriculture has brought a new direction for the development of agriculture [6]. It can not only effectively improve the agricultural ecological environment and

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significantly improve the efficiency of agricultural production, but also change the concepts of agricultural producers and consumers. The development of intelligent agriculture can also reduce production costs and realize scientific management while guaranteeing output by means of technology.

With the rapid development of Internet technology, the Internet of Things technology (IoT technology) has also emerged. Also, the information sharing has been realized by linking objects and people with the Internet through the functions of identification, induction, positioning and sensing [7]. On the one hand, it can improve economic benefits and save costs to the greatest extent; on the other hand, it can provide technical impetus for the recovery of the global economy. Nowadays, the IoT technology has been applied to many fields, such as transportation and logistics, industrial manufacturing, health care, intelligent environment, individuals and society [8]. It also solves many difficult problems. The combination of Internet of Things and agriculture will certainly help to solve the existing problems of low efficiency of agricultural infrastructure, and help to achieve the rapid and efficient development of agriculture.

The IoT technology is used to manage agriculture accurately and intelligently. Agricultural data can also be collected via the Internet of Things, and the big data processing technology is used to scientifically manage crops and related resources and equipment, thereby achieving efficient production process.

II. LITERATURE REVIEW

Agricultural information in foreign developed countries started earlier, and their research and application of intelligent agriculture are mature. Jeonghwan Hwang et al. developed and designed the agricultural environment monitoring service system [9]. The system used wireless sensor technology and GPS positioning technology to collect images of soil and crops, which realized the remote monitoring function of crop production, facilitated users to manage crops, and used solar power to ensure the normal operation of the equipment. The Climate Corporation integrated climate, geographical location and other related characteristics to provide natural disaster insurance services for farmers, so that agricultural production had a certain degree of protection [10]. After that, PepsiCo also developed a crop management system, which effectively improved crop yield and increased farmers' income [11]. In the process of scientific and technological development, China is also constantly learning from experience and actively developing agriculture, so that the agriculture will be modernized, intellectualized, data-based and informationized. Wen Fujiang proposed a platform for agricultural data sharing, which realized the sharing of data resources [12]. By collecting production data and real-time monitoring data, scholars of Zhejiang Academy of Agricultural Sciences designed and developed a network data platform for dynamic monitoring of agricultural resources, which enriched China's agricultural management system.

With the development of information, people are faced with a larger data system, which also attracts the attention of domestic and foreign scholars who have devoted themselves to the study of agricultural data. Lamehari et al. constructed the agricultural structure by analyzing the collected agricultural environmental data [13], which could help producers and intermediary companies make good decisions, optimize the decision-making process, and achieve the goal of improving agricultural productivity and scientific management of natural resources. Alves, Gabriel et al. developed and designed a system to monitor soil and analyze soil fertility, providing farmers with relevant recommendations for improving soil. Li Xiufeng et al. put forward a visual interactive system, which could provide users with network data services and facilitate data analysis [14].

III. METHODOLOGY

A. INTERNET OF THINGS

Internet of Things is a network that links all objects to achieve interconnection and interoperability based on Internet and traditional telecommunication network. Later, people interpreted it as a large number of end devices and facilities that were not limited by region. It included "internal intelligence" and "external enablement" [15]. Internal intelligence is mainly composed of sensors, mobile terminals, industrial systems, numerical control systems, home intelligent facilities, video surveillance systems and so on. External enablement refers to all kinds of assets such as tagged with RFID (Radio Frequency Identification), intelligent products such as individuals and vehicles with wireless terminals [16]. Through a variety of wireless or wired long-distance or short-distance networks for transmission, application integration, as well as cloud computing-based software and service operation mode, in the Internet, LAN and other environments, the use of appropriate information protection mechanisms can provide security and even personalized real-time online monitoring, GPS positioning traceability, early warning management, remote control, security prevention, remote maintenance, on-line upgrade etc. [17]. It has realized the integrated management of high efficiency, energy saving, safety and environmental protection.

In the practical application of the Internet of Things, four main technologies are designed: sensor technology, RFID technology, Quick Response Code and embedded system technology. Among them, sensor technology is a kind of detection device, which can sense the information of objects and convert the information it feels into signals or other forms for output according to certain rules, so as to realize the transmission, processing, recording and control requirements of information [18]. RFID technology is a comprehensive technology which combines radio frequency with embedded technology. It can identify automatically, having a wide range of applications and research in the field of logistics. Quick response code (QR code) is a recognition technology, and the information is displayed in the form of Quick Response

Code [19]. By getting information through the "Scan" function of mobile devices, Alipay and WeChat have received more payments. Embedded system technology refers to an operating system applied to small devices [20], which is a collection of computers, sensors, integrated circuits and so on. Because the embedded system only aims at a specific technology, designers can optimize it to reduce its size and cost.

The IoT architecture is generally divided into four layers: perception layer, network layer, processing layer and application layer. Among them, in the perception layer, sensors are mainly used for information recognition, such as RFID for obtaining electronic tags, so as to obtain the required front-end data [21]. The network layer refers to the background server that transmits information through the telecommunication network and the Internet. In the processing layer, some early warning, intelligent control and related prediction based on known data are implemented. The application layer is to process the information obtained by the perception layer, and to realize the product application through cloud computing, network services, etc.

B. INTELLIGENT AGRICULTURE

Intelligent agriculture is an intelligent system of agricultural experts, integrated control system of agricultural products and traceability system of organic agricultural products. It links the Internet platform and cloud computing method, realizes the digitalization of agricultural information, automation of agricultural production and intellectualization of agricultural management, so as to construct a modern green agricultural system with low carbon, energy saving, and high yield, and change the traditional farming way by means of science and technology [22]. Intelligent agriculture is the advanced stage of agricultural development. It relies on the business nodes of various industries on the production site, including data capture, early warning and real-time monitoring in the environment, artificial and crop growth stages. It also includes the monitoring of soil and water resources, as well as the screening and feeding standards of seeds, pesticides and fertilizers, so as to realize scientific production and lean management and improve the quality of cultivation and aquaculture of agricultural products.

On the one hand, intelligent agriculture can also use information technology to manage production process regularly and quantitatively, allocate resources according to local production conditions and growth conditions of agricultural products, reduce resource consumption, realize green agriculture, and guide the healthy development of agricultural market. On the other hand, the development of intelligent agriculture has also brought farmers a broader space for income [23]. As a result, farmers will not plant or sell blindly, and they will no longer plant in a strenuous way; there will be no marketing problems and any rotten situation for farmed agricultural products. It can also greatly enrich people's dishes, and people can have healthy food and good physical

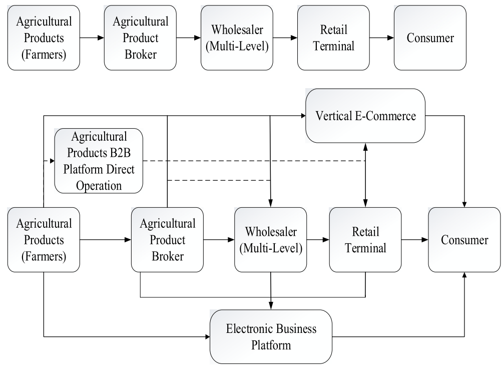

FIGURE 1. Traditional agricultural products circulation mode and agricultural products e-commerce mode.

conditions when they enjoy agricultural products and aquatic products. Therefore, the development of intelligent agriculture is an important step to achieve sustainable agricultural development. The traditional mode of agricultural products circulation and e-commerce is shown in Figure 1.

Traditional agricultural products cannot guarantee the quality of agricultural products after experiencing multi-level channels, and the time is longer, and the cost of manpower and material resources is higher. Of course, there are also many other problems, such as low utilization rate of arable land, backward agricultural infrastructure and low economic productivity of small farmers, which may lead to the vicious development of agriculture [24]. Once agriculture encounters more serious problems, the whole society will also suffer from crises. Therefore, considering the problems facing China's agricultural development, the combination of science and technology with agriculture, the reform of the Internet of Things model and the support of relevant national policies, it is essential to combine the Internet of Things and intelligent agriculture. The development process of intelligent agriculture is shown in Table 1.

The application of IoT technology in the field of intelligent agriculture can ensure the fine management of agricultural production, environmental monitoring of production and aquaculture, and management of the quality and safety of agricultural products. When problems occur, it can trace back to the source and form a management platform for agricultural production, animal husbandry and aquaculture in key areas to ensure the quality of agricultural products. The architecture of Internet of Things application in intelligent agriculture is shown in Figure 2.

C. GENERAL SITUATION OF AGRICULTURE IN JINSHA RIVER BASIN

Jinsha River is the upper reaches of the Yangtze River. It runs through 13 regions, including Yushu, Ganzi, Changdu, Diqing, Lijiang, Liangshan, Dali, Chuxiong, Panzhihua, Kunming, Qujing, Zhaotong and Yibin [25]. Because of the geographical advantages of the Jinsha River Basin, it has become the main channel and refuge for the bio-species from south to north in Eurasia, and is the most abundant

TABLE 1. Development process of intelligent agriculture.

Process	Characteristics
Traditional Agriculture	Manual management and lack of effective technical means to obtain the environmental parameters of crop growth; manual irrigation, water curtain, shading net, and exhaust fan control; time-consuming and laborious features and high error rate.
Intelligent Agriculture	Relatively single sensing data; data obtained by manual statistics and analysis; lack of intelligent data management and analysis platform; failure to achieve disaster early warning and application linkage.
Smart Agriculture	Sensing data diversification; integration of sensing, storage, analysis and linkage; remote monitoring and control; intelligent data processing and sharing; diversified alarm methods.

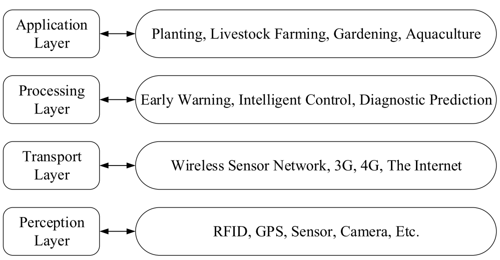

FIGURE 2. Internet of Things architecture of intelligent agriculture.

bio-community area in Eurasia. The abundant natural resources such as light, heat and land in Jinsha River Basin have attracted the attention of all parties, and further comprehensive agricultural development is under way. However, because the Jinsha River Basin is located in the mountainous area with steep slopes and is far from the central cities and towns, the utilization cost of many means of production and tools is high, which also increases the cost of agricultural production. Here, planting industry is the main industry, but farmers are confronted with issues such as weak agricultural machinery strength and lack of relevant scientific,

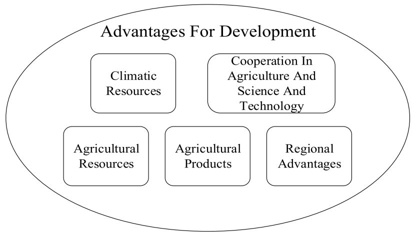

FIGURE 3. Advantages of developing agriculture in Jinsha River Basin.

technological and cultural knowledge; also, many agricultural technology service stations are on the shell, providing no technical support for farmers. Therefore, considering the abundant agricultural resources in Jinsha River Basin, people can rely on the unique geographical conditions to promote the development of ecological agriculture, realize agricultural modernization, and enhance the scale of production. A production base of high-quality agricultural products focusing on food security was formed, and the phased results were achieved in 2016, with a total agricultural output of 170.211 billion yuan, a planting area of 2954.29 thousand hectares and the total animal husbandry output of 141.906 billion yuan. The dominant factors of agricultural development in Jinsha River Basin are shown in Figure 3.

D. BIG DATA ANALYSIS

1) DATA VISUALIZATION

Data visualization is the study of the visual representation of data. It mainly uses the means of visualization to convey and communicate information clearly and effectively, and to achieve in-depth analysis of scattered and complex data sets through intuitive key features. Besides, the data interpreted by visualization technology can clearly and efficiently reflect the knowledge hidden in the data, so as to complete the transmission of data information and simplify understanding.

The data visualization tool is based on Spring framework, which consists of Web browser, Web server and SQL database. Web browser is the core part of this technology. It is mainly responsible for the interaction, parsing, data mapping, graphical display and selection of the visualization module, and realizes the data-driven page display of platform data and business logic. Web server realizes data interaction by analyzing user's requests, querying database and fetching relevant data from database, and transmitting them to front-end pages. SQL database is mainly responsible for storing related data. It can also query data through the database and cluster analysis of data results to provide support for the server. The hierarchy diagram is shown in Figure 4.

According to the processing results of data visualization module, different graphics can be generated, including the results of user requests directly, and the visualization scheme that can be referred to after some processing.

2) CLUSTER ANALYSIS

Cluster analysis refers to the process of combining and classifying abstract content according to its similarity. It is widely

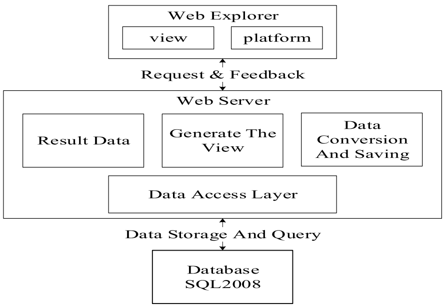

FIGURE 4. **Data visualization architecture diagram.**

used in mathematics, computer, statistics, biology and economics, and has achieved good results. Cluster analysis is a kind of exploratory analysis, so there is no fixed classification criterion in the process of exploring classification. It starts from the given sample data and classifies automatically. However, because there are many methods of clustering analysis, different clustering results may be obtained. Clustering analysis can be divided into hierarchical clustering and K-means clustering. Considering the large sample size of agricultural data, K-means clustering method is used.

The basic steps of K-means clustering analysis are to determine the number of categories K; to determine the initial clustering centers of K categories, and to calculate the Euclidean distance from each sample to K clustering centers in turn according to the determined initial clustering centers; then to divide all samples into the corresponding K categories according to the proximity principle; to calculate the mean of each variable in each category according to the K categories divided, and to calculate the Euclidean distance and reclassify from each sample to K clustering centers in turn according to the determined K categories taking the mean point as the new K class center, until the termination conditions are satisfied.

Set the sample X = {X1, X2, X3, ... Xn}, initialize K clustering centers {C1, C2, C3,... Ck}, and calculate the Euclidean distance from each sample variable to the cluster center.

$$\operatorname{dis}\left(X_i, C_j\right) = \sqrt{\sum_{t=1}^{m}\left(X_{it} - C_{jt}\right)^2} \tag{1}$$

In the above formula, X_i denotes the i-th object, X_{it} denotes the t-th attribute of the i-th object, C_j denotes the j-th cluster center, and C_{jt} denotes the t-th attribute of the j-th cluster center.

$$C_t = \frac{\sum_{X_i \in S_l} X_i}{|S_l|} \tag{2}$$

where, C_i denotes the i-th cluster center and $|S_l|$ refers to the number of objects in the i-th cluster. Since clustering analysis is a data iteration process that has been explored many times, it is necessary to specify a number of iterations to stop searching when this condition is satisfied:

$$F(X) = \sum_{i=1}^{K} \sum_{x \in C_I} \|X - C_i\|^2 \tag{3}$$

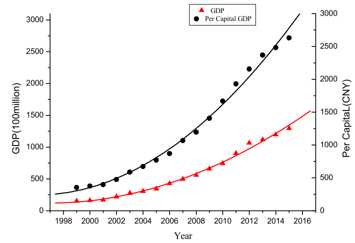

FIGURE 5. **Fitting curve of GDP and per capita GDP growth trend in Jinsha River Basin from 1999 to 2015.**

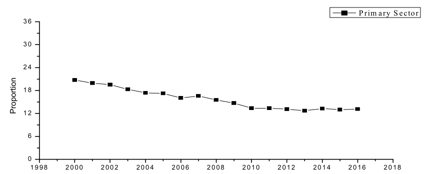

FIGURE 6. **Change trend of primary industry in Jinsha river basin from 2000 to 2016.**

IV. EXPERIMENT

A. RELEVANT DATA COLLECTION

Jinsha River Basin is located at the junction of Sichuan, Tibet, Qinghai, Yunnan and Guizhou. It has a relatively high terrain and a slightly fragile ecology. However, it has become the most abundant area of biological communities in Eurasia. Although the area is small, it has more than 20% of the higher plants and 25% of the total number of animals in the whole country. Therefore, as a resource-rich area in the western region, it has aroused great concern of the country. Through collecting relevant data of Jinsha River Basin, it is found that by 2016, the total production value of this region has reached 153.581 billion yuan, with an average per capita of 3330.7.18 yuan. Figure 5 is a fitting curve between GDP and per capita GDP growth trend in the Jinsha River basin from 1999 to 2015. The growth of primary industry in the Jinsha River basin is analyzed, as shown in Figure 6.

According to the trend of GDP and per capita GDP growth in Jinsha River Basin, although the long-term economic situation here is relatively weak, it shows a stable growth trend, which shows that its economic growth has certain vitality. The primary industry refers to all kinds of professional farmers and aquatic, native and other agricultural products, generally including agriculture, forestry, animal husbandry and fishery. However, the proportion of primary industry in the three major industries in Jinsha River basin is declining, which also shows that the production mode in this area is extensive and natural resources cannot be well utilized. Therefore, the data of crop sowing area in this area are further collected, as shown in Figures 7 and 8.

Note: 1 indicates the agricultural output value of each region (RMB 100 million) and 2 indicates the sown area of crops (1000 hectares).

In order to solve the existing problems of agriculture in the region, the IoT technology is used to precisely manage intelligent agriculture. The data of temperature and precipitation are also collected, as shown in Table 2.

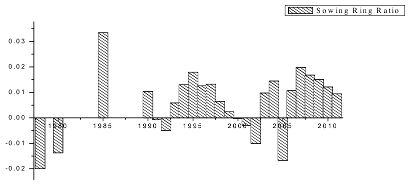

FIGURE 7. Ring ratio of crop planting area from 1978 to 2011.

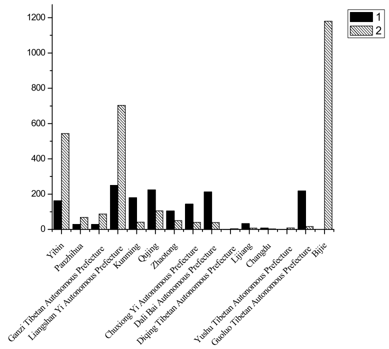

FIGURE 8. Agricultural and crop planting area in Jinsha river basin in 2016.

There are many technologies involved in the study of key technologies of intelligent agriculture, but in the practical application process of intelligent agriculture, it is necessary to find out the most critical three or four technologies and build an intelligent agricultural technology system. Among them, the technologies that may be used include: the design and implementation of agricultural perception technology and embedded intermediate software, the design and implementation of wireless Internet of Things gateway system, the data processing technology and traceability technology of monitoring data based on cloud platform, the design of sub-layer integration between networks, real-time data acquisition module, agricultural information data analysis technology, and design and implementation of automatic control module. Therefore, through data analysis and research on factors affecting crop growth, the key technologies of intelligent agriculture under the framework of Internet of Things are found, and more efficient technology for the development of intelligent agriculture are sought.

B. ANALYSIS OF INTELLIGENT AGRICULTURAL DATA IN JINSHA RIVER BASIN

Because agriculture is related to local temperature, precipitation, soil and sunshine, and the sample data is large, K-means cluster analysis in data analysis is used and the results are shown in Figure 9.

In Figure 9a, "1" represents that the mean annual temperature is 5.5-9oC, "2" suggests that the mean annual temperature is 4.5-5.5oC, and "3" indicates that the mean annual temperature is 10-18oC, and "4" is 0-4.5oC.

In Figure 9b, "1" indicates that the mean annual precipitation is more than 600 mm, "2" indicates that the mean annual precipitation is 500-600 mm, "3" indicates that the mean annual precipitation is 400-500 mm, and "4" indicates that the mean annual precipitation is less than 400 mm.

In Figure 9c, "1" indicates that the mean annual sunshine time is less than 2250 hours, "2" indicates that the mean

TABLE 2. Temperature and precipitation data in representative regions.

Fixed Point		DeGe	JiangDa	BaiYu	GongJue	MangKang	BaTang	DeRong
Average Annual Temperature (°C)		6.0	7.1	15.3	5	12.8	3.4	16.9
The Highest Extreme Temperature (°C)		31	18.8	38.2	16	39	26.8	33
The Lowest Extreme Temperature (°C)		-20.7	-11	-19	-28.4	-23	-24.6	-9
Average Monthly Maximum Temperature	Month	7	7	7	7	7	7	7
	Average Annual Temperature	14.5	16.1	15.8	14.1	19.2	21	7.9
Monthly Mean Minimum Temperature	Month	1	1	1	1	1	1	1
	Average Annual Temperature	-2.6	-0.6	-1.7	-1.2	3.3	2.5	5.5
Average Annual Precipitation (mm)		622	552	660	420.9	438.1	524.1	330.6
Annual Relative Humidity (%)		52	53	53	49	58	58	47
Annual Sunshine Duration (hours)		2043	2282	2130	2109	2606	2525	2986

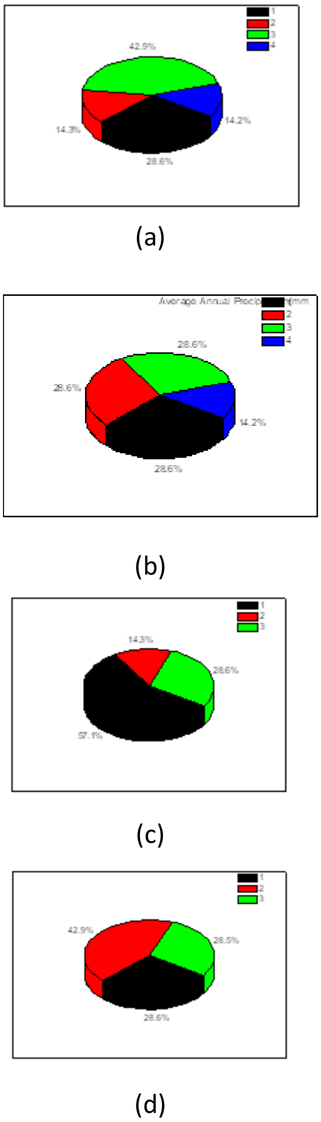

FIGURE 9. Clustering results of factors affecting agricultural Production.

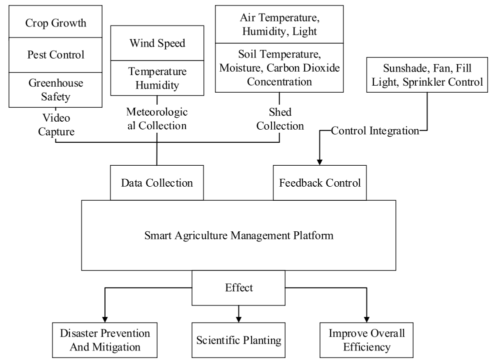

FIGURE 10. Intelligent agricultural management platform.

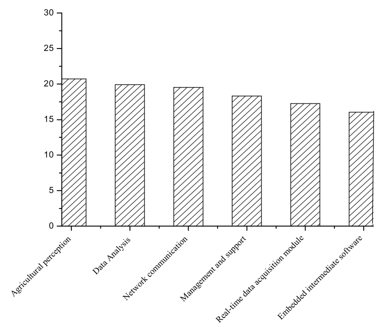

FIGURE 11. Proportion of technical importance.

annual sunshine time is more than 2700 hours, and "3" indicates that the mean annual sunshine time is 2250-2700 hours.

In Figure 9d, "1" indicates that the mean annual relative humidity is less than 50%, "2" indicates that the mean annual relative humidity is 50% - 55%, and "3" indicates that the mean annual relative humidity is 55% - 60%.

Visualization technology and RFID recognition technology are applied to collect data from the surrounding environment. Information is transferred to the cloud through network system. The cloud makes cluster processing of these data. Finally, this part of information is stored in the database and the data information is transferred to the equipment terminal. On the one hand, the crop status is transferred to users in the form of graphs, so that they can real-time monitor the growth of crops; on the other hand, this part of the information is transmitted to the equipment. The terminal equipment determines the demand of crops at this time according to the standards set by the internal embedded system, and carries out some nursing when necessary. Of course, the information stored in the database can be inquired in time when users need it, so that the root cause of the problem can be found and the problem can be solved quickly when the product has problems.

V. DISCUSSION

By analyzing the relevant factors affecting crop growth and the key technologies used by the Internet of Things in the development of intelligent agriculture, this study obtains the intelligent agriculture management platform, as shown in Figure 10.

In Figure 10, relevant data are obtained through front-end visualization technology, identification, sensing and monitoring technology of the Internet of Things, such as temperature, precipitation, humidity and sunshine. In actual sowing and management, certain adjustments are made according to crop growth conditions, such as controlling shade, fan, lighting time, etc. These data are processed through intelligent agricultural management system to find the best growth conditions of crops. At the same time, it is found that in the research of intelligent agriculture, equipment-side perception and identification technology, network communication technology, data analysis technology and management and support technology are the most critical, as shown in Figure 11.

According to Figure 11, the implementation of intelligent agriculture requires higher demands for data collection and analysis, network communication and management. Therefore, it is necessary to focus on the front-end induction and identification, to obtain more data, and to achieve disaster reduction and scientific planting as soon as possible in the future research, thereby ultimately improving the comprehensive benefits.

In summary, the related data are collected by the identification, sensing and visualization technology of the Internet of Things, and the data collected are processed by the relevant technology in the intelligent agricultural management platform, so as to find the most favorable environmental parameters for crop growth, effectively manage agricultural activities, realize the scheduling of resources, and ultimately realize the intelligent agricultural production and management. This paper only studies the early data acquisition and data processing of intelligent agriculture, but there may be some limitations in the specific application process, which lays a certain foundation for the subsequent quantitative research and further application, as well as the specific implementation of the front-end induction recognition technology and application.

VI. CONCLUSIONS

Agricultural informatization started earlier and developed faster in the developed countries, and a relatively perfect agricultural information technology system has been basically built. Nowadays, in this information age, the development of intelligent agriculture is more related to people's livelihood in China. Throughout the whole country, intelligent agricultural technology is implemented as a guideline for the development of modern agricultural construction. It is hoped that the gap between management and service fields can be narrowed through agricultural intellectualization, and the innovation of agricultural industry chain can be promoted comprehensively, so as to realize the agricultural information service in an all-round manner. At the same time, through intelligent agriculture, fine and efficient management of agriculture can be realized and the safety of agricultural products and the sustainable development of agriculture can be guaranteed. The IoT technology is used to construct the intelligent agriculture system, and the visual technology and clustering algorithm are used to analyze the factors affecting agricultural production, to find the key technology of sustainable development of intelligent agriculture, and to establish a convenient, high-quality and efficient agricultural production mode and intelligent agricultural management platform for modern agriculture. Through the relevant equipment, the needs of crops are perceived to carry out agricultural activities accurately, to achieve the management and scheduling of crops and resources and intelligent agricultural production. In addition, it also has a certain supporting role in the study of the front-end induction recognition technology.

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