Application Level Evaluation Index System and Model Construction of Agricultural IoT in the Whole Industrial Chain of Agriculture

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Abstract. This paper established the application level evaluation index system of agricultural IoT (Internet of Things) in the whole industrial chain of agriculture by means of the application of agricultural IoT in agricultural production, agricultural circulation, agricultural service and agricultural management. It determined the weight of each index by using the analytic hierarchy process, and then established the comprehensive evaluation model. The evaluation index was scored, and the practical application of the method was carried out by an example, which not only provides a scientific and comprehensive evaluation basis for the application level evaluation of IoT, but also provided a way for continuous optimization of the index system in the future.

1. Introduction

China is always the world's large agricultural country; agriculture has long been China's traditional and basic industry[1]. At present, IoT, big data, e-commerce and other Internet technologies are increasingly used in agricultural production. China's agriculture is in a new phase of transformation from traditional agriculture to modern agriculture regarding high-quality, high efficiency and high yield as the purpose[2].

Agricultural IoT uses RFID radio frequency identification system, middleware Savant system and Internet system to achieve automatic tracking of the whole process of production of agricultural products, production operation information of logistics through the installation of RFID reader on facilities of production, processing and transportation, warehousing, shelves and other logistics facilities so as to achieve theutomation and informatization of the entire agricultural production,

logistics process supervision and management of agricultural products[3]. Agricultural IoT technology can accelerate the transformation of traditional agriculture, improve agricultural production efficiency and agricultural resource utilization efficiency, optimize agricultural production and management level and effectively promote the transformation of traditional extensive agriculture to modern intelligent agriculture so as to provide unprecedented opportunities for agricultural informatization and development of intelligent agriculture[4-5].

The application level evaluation index system of agricultural IoT in the whole industrial chain of agriculture is a multi -hierarchy and multi - index compound system. In this compound system, the relative importance of each level and each index is different, it is necessary to evaluate the application level of agricultural IoT in the whole industrial chain of agriculture. Therefore, the establishment of a scientific and complete set of evaluation index system has a positive effect for the promotion of application of agricultural IoT in the whole agricultural industrial chain. In this paper, the application of agricultural IoT in the whole industrial chain of agriculture is divided into four aspects: agricultural production, agricultural circulation, agricultural service and agricultural management, and the construction includes the three - hierarchy agricultural standard evaluation index system of 1 general goal, 4 indexes of grade 1 and 18 indexes of grade 2. Use the analytic hierarchy process to determine the relative importance of the weight for describing the index system. When the matrix eigenvector is calculated, we can use the geometric mean method (square root method), arithmetic mean method (summation method), eigenvector method and least squares method. It has strong operability.

2. Application of IoT in Agriculture

2.1 Application of Internet of Things in agricultural production

The application of IoT technology makes the collection of environmental information data more accurate, intelligent, and the technology is used for growth environment monitoring, weather monitoring and pest monitoring of animals and plants. IoT technology can use temperature sensors, humidity sensors and CO_2 sensors to measure air humidity and temperature and CO_2 content; farmers can carry out scientific and effective monitoring and management of crops according to the measured data, and conduct real-time monitoring of temperature, humidity, light, soil moisture and other environmental factor data in the greenhouse, and implement intelligent decision-making with the support of the expert decision-making system, automatically control production equipment, or carry out real-time remote control of fan, heating and supplementing light equipment through computers, mobile phones and other terminals and adjust the growth environment in the greenhouse to the appropriate state; it can also be used for real-time collection of resource information in aquaculture area to achieve long-range regulation of aquaculture environmental factors and monitoring of water temperature, pH, dissolved oxygen and other physical and chemical factors at any time and monitor aquaculture water environment[6]; IoT technology can be used for remote diagnosis instead of experts or related personnel to solve the problem of crop pests and diseases[7], mainly provide pest video, pictures and other multimedia information query, agricultural experts online real-time diagnosis and consulting functions, and integrate the expert system technology, multimedia technology, network technology, solve the problem of remote diagnosis and consultation for pests and diseases, integrate the expert system diagnosis with quest of farmers and support the operation on the Internet[8]; research of IoT on plant information collection mainly includes acquisition of apparent visual information and internal information; apparent information is as follows: crop seedling growth, biomass, stem diameter, leaf area and other information; the internal information includes chlorophyll content, crop nitrogen, photosynthetic rate, seed vigor, leaf temperature and humidity. The monitoring of animal life information mainly includes body

temperature, body weight, behavior, quantity of motion, food consumption, and disease information of animals[9].

IoT technology can also affix electronic tags to the agricultural machinery, get real-time data of the location, speed, time, heading, operating conditions parameters, job management and operation statistics and others of agricultural machinery, understand the types of agricultural machinery and the number of supporting equipment so as to achieve the overall management of agricultural machinery[10].

2.2 Application of Internet of Things in Agricultural Circulation

Through the integrated use of IoT technology, the location tracking, source traceability, transportation, warehousing, circulation processing and other aspects of electronic operations of fresh agricultural products can be achieved; in particular, temperature and humidity monitoring can be carried out for the whole circulation process, which can effectively strengthen the communication of all aspects of cold chain logistics, improve the cold chain efficiency and prevent interruption of cold chain[11].

The main application of IoT in the processing of agricultural products is the making of electronic tags, electronic seals and electronic tags of transport vehicles, and inputting information into the system before the departure of the vehicle; deep processing enterprises read information through the electronic tags of agricultural products and add further processing information to the electronic tags of agricultural products[12]; IoT technology can also be used to optimize the retailer's inventory management, achieve zero inventory management, replenish in time, and realize real-time monitoring of the movement of goods and vehicle transport and improve retail management efficiency[13]; the application of IoT in the intelligent storage can accurately record and save inventory information in real time, automatically assign goods location, carry out real-time inventory check, query product location, summarize various inventory information, count the quantity and information of various incoming and outgoing products and predict the seasonal and cyclical demand for fresh agricultural products, etc.[14]; in the terminal seller part, according to the food processing technology, shelf life and the environmental parameters and the corresponding time recorded in circulation, provide the advice for order of supply for the seller and provide manufacturers with sales analysis report[15].

2.3 Application of IoT in agricultural services

Internet of Things can be used in agricultural information service system. In the aspect of agricultural production information, the application of IoT technology can find out problems in the process of crop growth and provide relevant decision-making suggestions through various related information service platforms. IoT can also provide information, data and news of agricultural products and other market information including management of agricultural products and market prediction information. The IoT can also be used to collect and disseminate more accurate and timely information of agricultural natural resources, which mainly include agricultural land resource information, water resource information and meteorological resource information[16].

2.4 Application of Internet of Things in Agricultural Management

The application of the IoT in the traceability of agricultural products follows GS1 bar code rules; in the sorting packaging, affix the only code to the fresh agricultural products so that consumers can trace the entire supply chain at the terminal; it includes product information, transport environment, circulation links and other information that consumers concern about, to a certain extent, which protect food safety[14]. Agricultural IoT can accurately get a lot of information in the field through

the remote monitoring technology in time, which breaks the limits of manual monitoring, enhances the timeliness of decision-making service, through the application of databases, expert systems and other technologies, makes early warning and response decision for unexpected adverse events in the field to maximize the protection of the normal growth of crops and prevent the occurrence of disasters and reduce losses[17]. Internet of things can implement intelligent diagnosis for animal (poultry) diseases and adopt modern information technology such as 3G, to achieve online diagnostic decision-making and remote consultation. According to local climate and epidemic and other factors, through the epidemic warning knowledge base, make an auxiliary warning for the animal epidemic[18].

3. Application level assessment of agricultural IoT based on AHP in the agricultural industrial chain

3.1 Theoretical and methodological basis

Analytic Hierarchy Process (AHP)[19-20] is a simple, flexible and practical multi-criteria decision-making method proposed by T.L.Saaty, an American operation research expert, in the early 1970s. It decomposes the composition of the problem according to its nature and the goal to be achieved. The factors are hierarchized according to the interrelationship of the factors and then form a hierarchical structure model. Then, analyze according to the hierarchy, the importance weight of the bottom hierarchy to the highest hierarchy (the general goal) is obtained[21].

3.2 General idea

Based on the application characteristics of the agricultural IoT in agricultural industrial chain and its composition, this paper adopts the analytic hierarchy process to construct the evaluation model of agricultural IoT in the whole industrial chain of agriculture; from its agricultural production, agricultural circulation, agricultural service, agricultural management and so on, through the selection of evaluation index, determine the weight of index of each hierarchy, establish the comprehensive evaluation model and carry out the scoring of relevant evaluation indexes by experts, calculation of data and analysis of results.

Table1 Application level evaluation index system of industrial IoT in the whole industrial chain of agriculture

Goal	Index of Grade 1	Index of Grade 2
A Application level of agricultural IoT in the whole industrial chain of agriculture A	Agricultural production C_1	Agricultural Production Environment monitoring Based on Internet of Things P_1 Monitoring of Animal and Plant Life body Based on Internet of Things P_2 Agricultural Intelligence Control and Management Based on Internet of Things P_3 Precise command and dispatch of agricultural machinery Based on Internet of Things P_4 Monitoring of Agricultural Production Process Based on Internet of Things P_5
	Agricultural circulation C_2	Monitoring of Agricultural Product Processing Based on Internet of Things P_6 Intelligent Storage of Agricultural Products Based on Internet of Things P_7 Cold chain logistics of agricultural products Based on Internet of Things P_8 Information Management of Agricultural Products Logistics and Transportation Based on Internet of Things P_9
	Agricultural service C_3	Data Analysis Service Based on Internet of Things P_{10} Agricultural Information Service Based on Internet of Things P_{11} Agricultural Product Market Information Service Based on Internet of Things P_{12} Agricultural Resource Information Service Based on Internet of Things Remote Interactive Training Service of Agricultural Experts Based on Internet of Things P_{14}
	Agricultural management C_4	Safety Traceability Management of Agricultural Products Based on Internet of Things P_{15} Agricultural Disaster Forecast Based on Internet of Things P_{16} Monitoring and Management of Agricultural Pollution Information Based on Internet of Things P_{17} Monitoring of Livestock and Poultry Diseases Based on Internet of Things P_{18}

As shown in Table 1, after full investigation of agricultural IoT demonstration area and test places, the final evaluation indexes are determined by experts through discussion. The application of agricultural IoT in the whole industrial chain of agriculture is divided into agricultural production C1, agricultural circulation C2 agricultural management C3 and agricultural management C4, in which, agricultural production C1 includes the agricultural production environment monitoring based on Internet of things P1, monitoring of animal and plant life body based on Internet of Things p2, agricultural intelligence control and management based on Internet of things P3, precise command and dispatch of agricultural machinery based on the Internet of things P4, monitoring of agricultural production process based on Internet of things P5, five indexes in total; agricultural production C2 includes monitoring of agricultural product processing based on Internet of Things P6,intelligent storage of agricultural products based on Internet of things P7, cold chain logistics of agricultural products based on Internet of things P8, information management of agricultural

products logistics based on Internet of things P9 , 4 indexes in total.The agricultural service C3 consists of five indexes: data analysis service based on the Internet of Things P10, agricultural information service based on the Internet of Things P11, agricultural product market information service based on the Internet of Things P12, agricultural resource information service based on the Internet of things P13, remote interactive training service of agricultural experts based on Internet of Things P14; Agricultural management C4 consists of four indexes: safety traceability management of agricultural products based on Internet of things P15, agricultural disaster forecast based on Internet of things P16, monitoring and management of agricultural pollution P17, information based on Internet of things P17 and monitoring of livestock and poultry diseases based on Internet of things P18. And finally form the three- hierarchy application level evaluation index system of agricultural IoT of a general goal, 4 indexes of grade 1and 18 indexes of grade 2 [22].

3.4 Determination of the weight of evaluation index

Discussed by experts, according to the Scale definition table (Table 2), determine the relative importance of index layer among various factors to form the first grade index judgment matrix; use the arithmetic mean method (root method) to determine the weight of the evaluation index and conduct the consistency test (Table 4).

Table2 Scale definition table

Scale a_{ij}	Definition
1	Indicate that factor i is as important as factor j
3	Indicate that factor i is slightly more important than factor j
5	Indicate that factor i is more important than factor j
7	Indicate that factor i is much more important than factor j
9	Indicate that factor i is absolutely important than factor j
2，4，6，8	It is the corresponding scale value of the intermediate state between above two judgments
Reciprocal	If factor i is compared with factor j the judgment value is $a_{ji} = 1/a_{ij}$， $a_{ij} = 1$

Table3 Value of random consistency index RI

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table4 Judgment matrix A-C

A	C_1	C_2	C_3	C_4	W_i	Consistency Test
C_1	1	3	2	3	0.4550	CR=0.003836 CR<0.1 Pass
C_2	1/3	1	1/2	1	0.1411	
C_3	1/2	2	1	2	0.2627	
C_4	1/3	1	1/2	1	0.1411	

Similarly, according to the importance of each factor of the index layer, construct the second grade index judgment matrix, determine the weight of the evaluation index and conduct the consistency test (Table 5 - Table 8).

Table5 Judgment matrix C1-P

C_1	P_1	P_2	P_3	P_4	P_5	W_i	Consistency Test
P_1	1	2	3	3	1	0.3134	CR=0.0030 CR<0.1 Pass
P_2	1/2	1	2	2	1/2	0.1758	
P_3	1/3	1/2	1	1	1/3	0.0986	
P_4	1/3	1/2	1	1	1/3	0.0986	
P_5	1	2	3	3	1	0.3134	

Table6 Judgment matrix C2-P

C_2	P_6	P_7	P_8	P_9	W_i	Consistency Test
P_6	1	2	3	3	0.4118	CR=0.0180 CR<0.1 Pass
P_7	1/2	1	2	2	0.2654	
P_8	1/3	1/2	1	1	0.1614	
P_9	1/3	1/2	1	1	0.1614	

Table7 Judgment matrix C3-P

C_3	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	W_i	Consistency Test
P_{10}	1	1/3	3	1/2	2	0.1578	CR=0.02934 CR<0.1 Pass
P_{11}	3	1	5	2	7	0.4597	
P_{12}	1/3	1/5	1	1/2	2	0.0918	
P_{13}	2	1/2	2	1	3	0.2258	
P_{14}	1/2	1/7	1/2	1/3	1	0.0650	

Table8 Judgment matrix C4-P

C_4	P_{15}	P_{16}	P_{17}	P_{18}	W_i	Consistency Test
P_{15}	1	2	5	3	0.4360	CR=0.02916 CR<0.1 Pass
P_{16}	1/2	1	3	2	0.2750	
P_{17}	1/5	1/3	1	1/2	0.1118	
P_{18}	1/3	1/2	2	1	0.1772	

The weight of importance of all the factors of this layer for the previous layer can be calculated by means of the results of the single sort of all the layers of the same layer. The general sort of the layers needs to be carried out from top to bottom layer by layer; the general sort of layers can be calculated, namely, the weighting vector of the application level evaluation index system A of the second grade index P_i for agricultural IoT in the agricultural industrial chain. The results are as follows:

Table 9 Application level evaluation index weight of the agricultural IoT in the whole industrial chain of agriculture.

Index of grade 1		C_1	C_2	C_3	C_4	Weight of second grade index relative to the general goal
		0.4550	0.1411	0.2627	0.1411	
Index of grade 2	P_1	0.3134				0.1426
	P_2	0.1758				0.0800
	P_3	0.0986				0.0449
	P_4	0.0986				0.0449
	P_5	0.3134				0.1426
	P_6		0.4118			0.0581
	P_7		0.2654			0.0375
	P_8		0.1614			0.0228
	P_9		0.1614			0.0228
	P_{10}			0.1578		0.0414
	P_{11}			0.4597		0.1208
	P_{12}			0.0918		0.0241
	P_{13}			0.2258		0.0593
	P_{14}			0.0650		0.0171
	P_{15}				0.4360	0.0615
	P_{16}				0.2750	0.0388
	P_{17}				0.1118	0.0158
	P_{18}				0.1772	0.0250

Consistency indexes are:

$CR=\sum_{i=1}^{n} \alpha_i CI_i / \sum_{i=1}^{n} \alpha_i RI_i=0.01525<0.1$

Among them, CI_i is a consistency index of single order, the single order consistency index of P_i for C_i; RI_i is the corresponding average random consistency index. The result of the total ordering is satisfactory.

The above index vector is the weight of the application level assessment index, which provides prerequisite for the application level assessment practice in the agricultural industrial chain.

3.5 Comprehensive evaluation model

The comprehensive evaluation is calculated according to the weighted summation of each index, ie: $z=\sum_{i=1}^{n} (w_i \frac{1}{k} \sum_{i=1}^{k} F_{ij})$

Where: k is the number of evaluation experts, W_i is the combination weight of each index, F_{ij} is the actual evaluation of index by expert No j. The scoring rules of the actual evaluation index by experts are as follows:

Indexes of grade 2 are divided into five grades: very poor, poor, common, good and very good; the score evaluation is shown in Table 10.

Table10 Evaluation index score interval

Grade	Score interval
Very poor	0 ～ 25
Poor	25 ～ 50
Common	50 ～ 75
Good	75 ～ 90
Very good	90 ～ 100

4. Case analysis

Wen County Huai Iron Stick Yam IoT application demonstration area was determined as the first batch of "Three products and one standard" creation institution in 2013 and " "Wen county 1000 acres wisdom Huai yam IoT monitoring agricultural information institution of " The top ten constructions" of Jiaozuo City (2013 - 2015) " by Henan Province Agriculture Department and was included in the demonstration projects by Henan Province Department of Industry and Information in 2014. 10 experts were organized to score and evaluate; the final score results are shown in Table 11.

Table11 Final score results of IoT application demonstration area

Index of grade 2 P	Expert score (Average)	Index of grade 1 C	General goal A
P_1、P_2、P_3、P_4、P_5	95.2、90、92.5、93.5、95	93.77	88.09
P_6、P_7、P_8、P_9	93、85、86.5、94	89.99	
P_{10}、P_{11}、P_{12}、P_{13}、P_{14}	86.5、95、88、83.5、95	90.43	
P_{15}、P_{16}、P_{17}、P_{18}	90、88.5、0、0	63.58	

In this evaluation, we selected Wen county huai yam IoT application demonstration area for the application level evaluation of the IoT. From the evaluation index of grade 1, we can know that the application level evaluation of agricultural IoT in agricultural industrial chain is that the level of agricultural production is higher than that of agricultural service, which is higher than that of agricultural circulation, which is higher than that of agricultural management. The final score of this evaluation is 88.09, belonging to a better level of the application level of agricultural IoT.

5. Conclusion

On the basis of the theoretical research on the application of agricultural IoT in the agricultural industrial chain, this paper uses the analytic hierarchy process to determine the weight of each index factor and constructs the application level evaluation model of agricultural IoT in agricultural industrial chain. The data are collected in the mode of scoring. Examples are analysed to further explain and validate the evaluation model, so as to provide certain reference value for the application level evaluation of agricultural IoT in the whole industrial chain of agriculture.

In practice, the assessment experts rely on rich professional knowledge and experience to score, but the score is inevitably subjective, which has certain impact on the assessment results. It is suggested to further refine the score judgment standard of the evaluation index, reduce the influence of the evaluation index and objectivity of experts on the evaluation result and improve the rationality and objectivity of the evaluation method.

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