J. COMBIN. MATH. COMBIN. COMPUT. 127b (2025) 1877--1894

Journal of Combinatorial Mathematics
and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Combinatorial Press

Internet of Things Technology in Development of Rural Characteristic Ecological Agriculture

Jingjing Yan[1], Qingfeng Bao[1,✉], Dongfeng Gao[2]

[1] *School of Economics and Management, Inner Mongolia Agricultural University, Hohhot, Inner Mongolia, 010010, China*

[2] *Inner Mongolia People's Anti-Air Defense Command and Information Assurance Center, Hohhot, Inner Mongolia, 010010, China*

ABSTRACT

As a result of continuous economic development and accelerated urbanization, the agriculture development has had to change from the traditional mode of agricultural production to the modern mode of agricultural production. What kind of method can better help the development of modern agricultural production mode has become one of the current research topics that has attracted much attention. In response to this problem, the field of modern agricultural production models becomes highly relevant for research. With the in-depth study of modern agricultural production, the research on Internet of Things (IoT) technology in rural characteristic ecological agriculture (ECO) is gradually carried out, and its functional advantages are of great significance to promote the development of modern agriculture. This paper aimed to study the application of IoT technology in the development of rural characteristic ECO. The analysis and research of IoT and ECO enables it to be applied to the construction of an ecological farmland information monitoring system to address the problem of enhancing the ECO development with rural characteristics. In this paper, IoT technology, information detection and ECO were analyzed; the performance of the method was experimentally analyzed; the relevant theoretical formulas were utilized for interpretation. The outcomes demonstrated that the incidence of pests and diseases in field A using the IoT-assisted information monitoring system was 31.11% lower than that in field B, and the use of pesticides was reduced by 15.69%. It can be learned that IoT technology can meet the needs of enhancing the development level of rural characteristic ECO, and the level of agricultural development and work efficiency have been greatly improved.

Keywords: Eco-agriculture with Rural Characteristics, Internet of Things Technology, Information Monitoring, Rural Revitalization

1. Introduction

At the present stage of agricultural development mainly need to face two aspects of the problem. First of all, the agricultural production process of low technology content, scientific and technological

✉ Corresponding author.
E-mail address: bqf1183@163.com (Q. Bao).
Received 30 May 2024; Revised 15 August 2024; Accepted 10 January 2025; Published Online 16 April 2025.
DOI: 10.61091/jcmcc127b-105

agricultural equipment configuration is not perfect, which not only makes the labor intensity of the working people, low efficiency, but also need to “rely on the sky to eat”, crop yields are also very unstable [1-3]. Secondly, there is a large amount of pollution and waste in agricultural production, pesticides and water use is growing rapidly every year, the use of data is very alarming, but also lead to the rural areas around the drinking water resources are affected by the drug [4-6]. These problems, to the development of special ecological agriculture and the most basic farmland protection has brought many negative impacts, but also increased the difficulty of environmental protection and governance work.

Accompanied by the rapid development of science and technology in China, the Internet is increasingly being emphasized, and the third wave of the scientific and technological revolution represented by information technology has come quietly. Agricultural science and technology is an important support for the development of characteristic ecological agriculture [7]. The application of IoT technology to the development of modern ecological agriculture with special characteristics can play a role in reducing agricultural costs, improving farmers' income and protecting the agro-ecological environment [8-9]. And with the popularization and application of IoT technology in the fields of agricultural information transmission, intelligent cultivation, safety management traceability and agricultural products sales, the development level of agricultural modernization and informationization is also improving [10-12]. With the popularization and application of IoT technology, it can also promote the implementation of standardized production in agriculture and provide basic data for agricultural production and carrying out disaster and pest prevention through effective monitoring of the agro-ecological environment [13-15]. Especially in the use of pesticides and fertilizers, with the support of modern advanced science and technology, it is possible to prevent excessive overdose, but also reduce the damage to the agro-ecological environment, laying a good foundation for the healthy and sustainable development of modern agriculture [16-18].

Literature [19] designed a platform integrating IoT, cloud computing, data mining and other technologies, which is able to realize the functions of the agricultural IoT monitoring system and provide important technical support for improving the efficiency of modern agricultural production as well as reducing the pollution of agricultural activities. Literature [20] constructs an agricultural product circulation information system based on 5G IoT, which not only provides accurate information sharing services for producers, distributors and consumers, and guarantees the quality and safety of e-commerce agricultural products, but also effectively reduces and improves the efficiency of agricultural product circulation and transportation costs, and promotes the sustainable development of agriculture. Literature [21] developed a set of intelligent agriculture system using IoT technology, and combined with data visualization analysis and cluster analysis technology to make agricultural activities scientific and standardized, which not only saves the time cost of farmers, but also improves the yield of crops and realizes the efficient development of agriculture. Literature [22] emphasizes that the development of precision agriculture helps to coordinate agricultural productivity and environmental integrity, and smart agricultural systems based on technologies such as the Internet of Things (IoT) can guide agricultural activities based on crop growth environments and growth data, which ensures the efficiency of agricultural technology and the accuracy of yield prediction, and also reduces the damage to natural ecosystems. Literature [23] analyzes the outstanding advantages and challenges of wireless sensor-based IoT agriculture, a series of tools and devices can help farmers to monitor the crops from sowing to harvesting stage, and contribute to the sustainable development of agriculture. Literature [24] shows that IoT can help to meet the requirements of eco-centered sustainable agriculture by deploying wireless sensors for continuous monitoring of production units and their near and far environments, as well as connecting and communicating the devices with cloud computing and artificial intelligence to generate optimal decisions.

To address the issue that the development level of ECO with rural characteristics is not high, this paper uses IoT to analyze ECO, and simulates the system to achieve the effect of efficient monitoring of field data. The innovation of this paper is to use IoT and ECO to analyze how IoT technology and data monitoring technology play a role in the research on the development of rural characteristic ECO. The proposed rural characteristic ecological agricultural field information monitoring system is expounded. The experiments have revealed the system's excellent performance and greater practicality, greatly improving the agricultural production efficiency.

2. Methods of Development of ECO with Rural Characteristics

Encouraging the transition to ECO can promote faster and better development of rural characteristic agriculture. Traditional rural agricultural production has been in the artificial stage for a long time, but there are many problems in the traditional artificial rural agricultural mode. Therefore, the research on the development of rural characteristic ECO is very important. Traditional rural agriculture is shown in Figure 1:

Fig. 1. Traditional rural farming

The survey reveals that the current research on the development of IoT technology in rural ECO is not complete, so this paper presents a study on information monitoring of rural ECO fields using IoT technology. This paper analyzes the related methods of IoT, information monitoring and ECO, and proposes related methods for rural characteristic ECO field information monitoring. The experimental analysis demonstrates that this method can enhance the development level of rural characteristic ECO.

2.1. Iot Assists Development of Rural Characteristic ECO

The proposal of modern agricultural development strategy is gradually drawing people's attention to rural ECO, and traditional rural agriculture is being transformed into intelligent ECO. As the information age continues to evolve, IoT technology has emerged. Every big and small thing in people's life and production is connected in some form and plays a role in various fields. The application areas of IoT technology are illustrated in Figure 2:

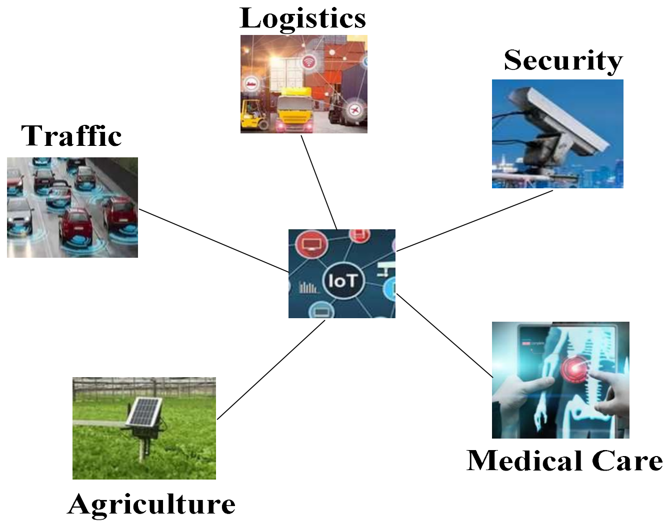


Fig. 2. Application of IoT technology

As shown in Figure 2: In the aspect of transportation, the intelligent transportation system is used to improve the road environment and traffic safety; in the field of logistics, the computer and IoT technology are used for data analysis and problem solving to complete the pre-scheduling of logistics and transportation. In terms of security, the use of intelligent security systems makes up for the shortcomings of traditional security methods such as large demand for personnel and high workload. In the medical field, various indicators of patients are managed through IoT technology, which can be used to monitor the status of patients or doctors. In agriculture, IoT is closely integrated with modern agricultural technology. By collecting real-time values for visual analysis, the existing planting process is systematically controlled to achieve the effect of precise management.

In this paper, the application of IoT technology in agricultural production forms the Agricultural IoT. IoT combines all aspects of agricultural production to realize real-time monitoring and effective control of the entire agricultural production process. The combination of IoT technology and agricultural production processes can timely and accurately monitor crop growth information, ensure the healthy growth of crops, and promote the rapid development of rural ECO. However, due to the large amount of cultivated land in remote villages, the degree of agricultural production concentration is not high, and a variety of crops are grown on the same piece of land, it is difficult to collect and publish information. To address the issue of information data, this paper applies the long-distance radio (LoRa) wireless network transmission technology to combine the actual production situation, and designs a rural characteristic ECO information monitoring system to enhance the information monitoring system's stability and reduce the system cost. Compared with several wireless technologies currently commonly used, LoRa has significant advantages in long-distance transmission. Using LoRa technology to address the issue of farmland information collection and management would be of great significance to promote the development of rural characteristic ECO. The performance comparison of several wireless technologies is shown in Table 1:

Table 1. Performance comparison of different wireless technologies

Type of technology	Cost	Maximum rate	Coverage distance	Frequency band	Power consumption	Network node
LoRa	low	0.0037	>1000	0.137-1.020	very low	>1000
Bluetooth	mediu	1.00	50	2.4	medium	127

	m					
ZigBee	low	0.25	75	2.4	very low	225
Wi-Fi	mediu m	1.00	50	2.4	high	50

By comparing the usage cost, maximum speed, coverage distance, power consumption, and number of network nodes of different wireless technologies, it can be seen that the LoRa gateway can simultaneously receive and process data from multiple sensor nodes using a large network capacity. The linear transmission distance of LoRa can reach more than 1000 meters, and complete demodulation can be achieved when the signal-to-noise ratio is less than 20dB. Since the power consumption of LoRa wireless networking technology is very low, the running current is only a few milliamps and the sleep current is less than 200 nanoamps. This would greatly increase the operating time of the device. LoRa not only has very low power consumption and use cost, but also covers a very long distance, which is very suitable for large-area field information monitoring. The principle of LoRa communication is shown in Figure 3:

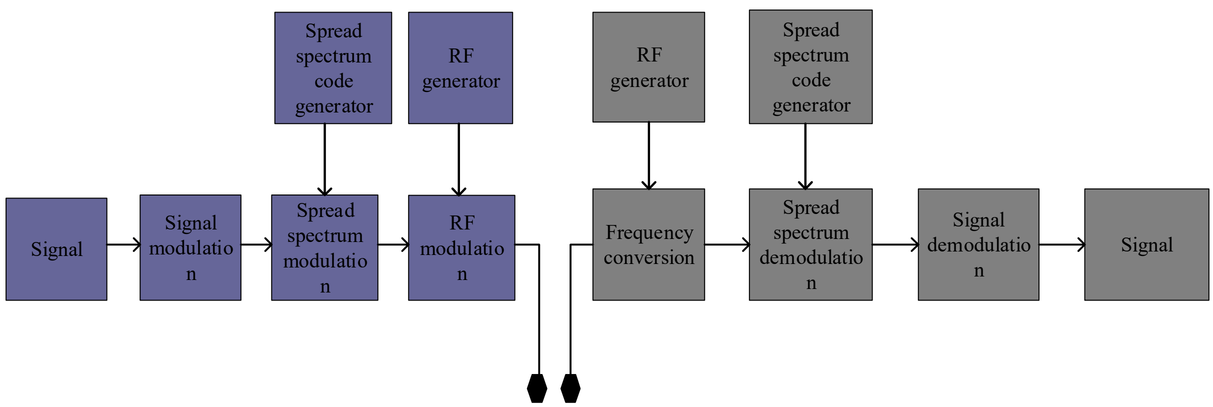


Fig. 3. LoRa communication principle

As shown in Figure 3: The principle of LoRa spread spectrum communication is to use spread spectrum technology to spread the signal into broadband noise to obtain spread spectrum gain. LoRa modulates signals at the physical layer to be compatible with more communication protocols and various network types. The gateway of the LoRa communication network supports multiple end nodes and can receive data in parallel, thereby increasing the system capacity.

The information monitoring system constructed in this paper is based on agricultural IoT technology. In this paper, three subsystems of information acquisition terminal, LoRa gateway and information monitoring terminal are respectively constructed. The information collection terminal is the basis of the information monitoring system composed of sensor nodes installed in the agricultural environment. The real-time data of the agricultural environment can be obtained through various sensors, and the collected data can be sent to the LoRa gateway through the LoRa communication module. The LoRa gateway is responsible for the overall transmission of data, and plays the role of connecting the information collection terminal and the information monitoring terminal. The key technology of LoRa gateway is LoRa wireless transmission technology. The LoRa wireless communication terminal module sends the collected data to the LoRa gateway through the wireless network. The LoRa gateway analyzes the data, and performs comprehensive and standardized processing and storage for the information monitoring terminal. The information monitoring terminal mainly reads the server data through the host to realize the visual display of the farmland information data. After parsing the displayed data, it continues to issue control commands to realize digital control of farmland. In this process, the control commands of the application layer to agricultural facilities are sent to the information collection terminal through the LoRa gateway to realize the adjustment of the agricultural environment. Figure 4 shows the system's basic structure:

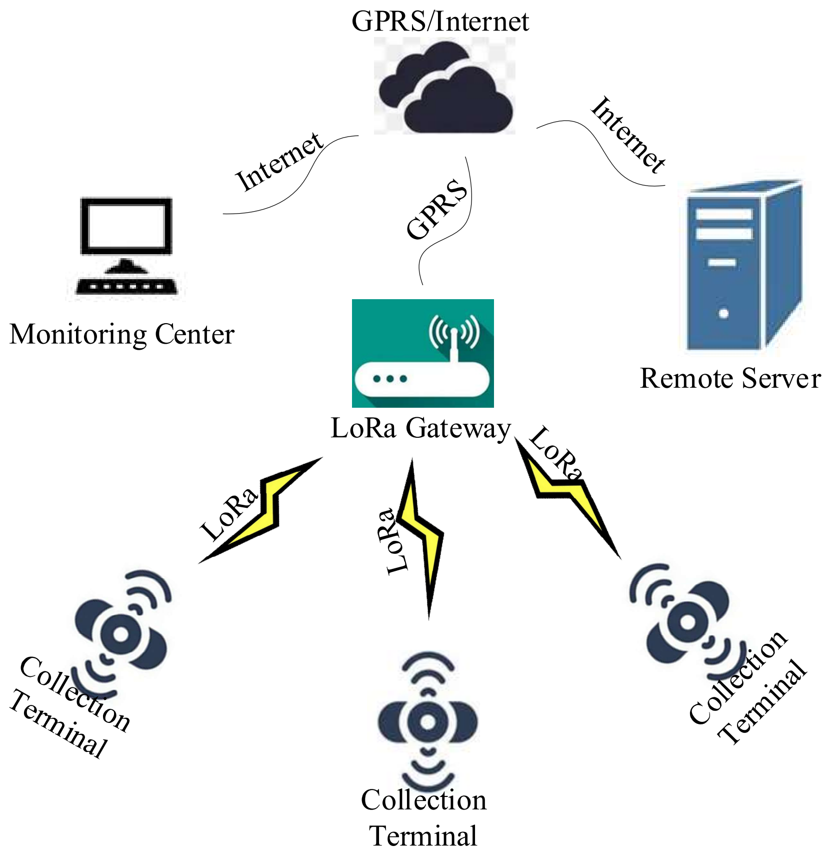


Fig. 4. System basic structure

In this system, the farmland information acquisition sensor adopts the star topology to form the information acquisition terminal, and the information acquisition terminal can automatically form a wireless network during the operation. The LoRa gateway mainly includes the LoRa wireless network, the serial communication link between the capture terminal and the LoRa gateway, and the network interaction link between the GPRS network and the Internet. The information monitoring terminal is divided into on-site man-machine dialogue interface and remote man-machine dialogue interface. The LoRa gateway can send data to the cloud via GPRS. Monitoring centers and remote online users can connect to the cloud through the Internet to monitor data in real time anytime, anywhere. The acquisition parameters of the terminal sensor can be changed by the remote control function.

2.2. Multi-sensor Data Fusion Technology of ECO

As the name suggests, multi-sensor data fusion is the process of processing the information collected by sensors through data fusion technology. Data fusion processing technology is a new type of interdisciplinary technology, which is mainly used to comprehensively and integratively process massive data and generate various results by analyzing the data. A large amount of agricultural data needs to be processed in the ECO information monitoring system. To enhance the data processing efficiency, this paper applies the multi-sensor data fusion technology to the farmland information monitoring system.

The multi-sensor data fusion technology designed in this paper is designed for the information fusion of the unique ecological agricultural environment in the countryside. In the process of data collection, a very large amount of data would be generated, and the data accuracy is not high. To realize the ECO information monitoring system's requirements for the collection accuracy, this paper adopts the data-level fusion method to fuse the agricultural environmental data. By directly fusing the original data, the influence of interference can be effectively eliminated, and accurate fusion data results can be obtained.

The process by using the adaptive weighted fusion algorithm is as follows: first, the initial measurement values of each sensor are obtained, then the variance of these values is calculated, and finally the corresponding optimal weight is obtained by summing the error mean. Adaptive methods can multiply the initial value by the optimal weight to obtain the optimal value after fusion. The relationship between the obtained fusion result and the weight is shown in formula (1):

$$\begin{cases} \hat{\mathrm{R}} = \sum_{i=1}^{n} Q_i R_i \\ \sum_{i=1}^{n} Q_i = 1 \end{cases} \tag{1}$$

Among them, $\hat{\mathrm{R}}$ is the fusion result value; Q is the weighted value of the sensor; R is the sensor acquisition value;

Then to calculate the total mean square error (MSE) value, the process is shown in formula (2):

$$\begin{aligned} \alpha^2 &= W[(R-\hat{R})^2] \\ &= W[(\sum_{i=1}^{n} Q_i R - \sum_{i=1}^{n} Q_i R_i)^2] \\ &= W[\sum_{i=1}^{n} Q_i^2 (R-R_i)^2 + 2\sum_{i=1,j=1}^{n} Q_i Q_j (R-R_i)(R-R_j)] \end{aligned} \tag{2}$$

Among them, W is the data characteristic parameter. Since the R values are independent values and are all unbiased estimates, the following conditions are satisfied, as shown in formula (3):

$$\begin{Bmatrix} W(R-R_i)(R-R_j) = 0 \\ i = 1,2,\ldots,n; j = 1,2,\ldots,n; i \neq j \end{Bmatrix} \tag{3}$$

Then the value of the total MSE at this time can be expressed by formula (4):

$$\alpha^2 = W\left[\sum_{i=1}^{n} Q_i^2 (R-R_i)^2\right] = \sum_{n=1}^{n} Q_i^2 \alpha_i^2 \tag{4}$$

According to the characteristics of the multivariate quadratic formula, the corresponding weighted value when the minimum value of the total MSE is obtained is the optimal value, then the formula (1) is transformed to obtain the formula (5):

$$\begin{cases} f(Q_i)_{\min} = \sum_{i=1}^{n} Q_i^2 \alpha_i^2 \\ \sum_{i=1}^{n} Q_i = 1 \end{cases} \tag{5}$$

The following function is constructed using the Lagrange multiplier method, as shown in formula (6):

$$\begin{cases} F(Q_i) = f(Q_i) + \beta\chi(Q_i) \\ \chi(Q_i) = \sum_{i=1}^{n} Q_i - 1 \end{cases} \tag{6}$$

Formula (5) is substituted into Formula (6) and the partial derivative of W is obtained as shown in Formula (7):

$$\begin{cases} \dfrac{\delta F}{\delta Q_1} = 2Q_1\alpha_1^2 + \beta \\ \dfrac{\delta F}{\delta Q_2} = 2Q_2\alpha_2^2 + \beta \\ \quad \cdots \\ \dfrac{\delta F}{\delta Q_n} = 2Q_n\alpha_n^2 + \beta \end{cases} \tag{7}$$

Let $\dfrac{\delta F}{\delta Q_n} = 0$, then we get as shown in formula (8):

$$\begin{cases} 2Q_1\alpha_1^2 + \beta = 0 \\ 2Q_2\alpha_2^2 + \beta = 0 \\ \quad \cdots \\ 2Q_n\alpha_n^2 + \beta = 0 \end{cases} \tag{8}$$

By converting formula (8) to formula (9):

$$\begin{cases} Q_1 = \dfrac{1}{\alpha_1^2 \sum_{i=1}^{n} \frac{1}{\alpha_i^2}} \\ Q_2 = \dfrac{1}{\alpha_2^2 \sum_{i=1}^{n} \frac{1}{\alpha_i^2}} \\ \quad \cdots \\ Q_n = \dfrac{1}{\alpha_n^2 \sum_{i=1}^{n} \frac{1}{\alpha_i^2}} \end{cases} \tag{9}$$

From formula (9), it can be inferred that when the minimum total MSE value is obtained, the optimal weight is shown in formula (10):

$$Q_i^* = \frac{1}{\alpha_i^2 \sum_{i=1}^{n} \frac{1}{\alpha_i^2}}, i = 1, 2, \ldots, n \tag{10}$$

According to the above formula, the minimum value of the total MSE is calculated as shown in formula (11):

$$\alpha_{\min}^2 = \frac{1}{\sum_{i=1}^{n} \frac{1}{\alpha_i^2}} \tag{11}$$

The calculation process of the average value of sensor data is shown in formula (12):

$$\overline{R}(c) = \frac{1}{c} \sum_{j=1}^{c} R_j(j) \tag{12}$$

c is the number of sensor measurements.

The calculation process of the estimated value is shown in formula (13):

$$\overline{R} = \sum_{i=1}^{n} Q_i \overline{R}(c) \tag{13}$$

The total MSE is calculated as shown in formula (14):

$$\begin{aligned}\bar{\alpha}^2 &= W[(R-\bar{R})^2] \\ &= W[\sum_{i=1}^{n} W_i^2 (R-R_i(c))^2 + 2\sum_{i=1}^{n} (R+\bar{R}_i(c))(R-\bar{R}_j(c))]\end{aligned} \tag{14}$$

In order for a person to calculate the optimal weighting value, the person must first obtain the variance value of each sensor. The variance value is obtained by sensor measurement. The measured value of the sensor can be expressed by formula (15):

$$\begin{cases} r_i = R + w_i \\ r_i = R + w_j \end{cases} \tag{15}$$

Among them, i, j are two different sensors; w is the measurement error of the sensor.

When the situation in the environment is zero-mean stationary noise, the sensor variance is calculated as shown in formula (16):

$$\alpha_i^2 = W[w_i^2] \quad (16$$

Since the error mean is 0 and has no relationship with the R value, the covariance function of the two different sensor measurements is given by formula (17):

$$X_{ij} = W[r_i r_j] = W[R^2] \tag{17}$$

Then the autocovariance function of r_i is shown in formula (18):

$$X_{ii} = W[r_i r_j] = W[R^2] + W[w_i^2] \tag{18}$$

Subtracting formula (18) from formula (17) yields formula (19):

$$\alpha_i^2 = W(w_i^2) = X_{ii} - X_{ij} \tag{19}$$

Among them, the value of X_{ii}, X_{ij} are obtained by considering the value in the time domain. The time domain estimates are calculated as shown in formulas (20) (21):

$$X_{ii}(c) = \frac{c-1}{c} X_{ii}(c-1) + \frac{1}{c} r_i(c) r_i(c) \tag{20}$$

$$X_{ij}(c) = \frac{k-1}{k} X_{ij}(k-1) + \frac{1}{k} r_i(c) r_j(c) \tag{21}$$

Using the mean value of $X_{ij}(c)$ to replace the value of X_{ij}, the covariance calculation formula is obtained as shown in formula (22):

$$X_{ij} = \bar{X}_{ij}(c) = \frac{1}{n-1} \sum_{i \neq j, i=1}^{n} X_{ij}(c) \tag{22}$$

Among them, n is the sensor ordinal number.

Through the analysis of the above steps, a time-domain estimate can be obtained from the measurements of each sensor, and then an adaptive weighted data fusion algorithm is used to fuse each sensor's variance estimate with the data collected by the sensor. In this paper, the proposed algorithm is tested for data monitoring of ECO through experiments.

3. Data Sources for Development of ECO with Rural Characteristics

The data collection used to test the algorithm is located in a greenhouse, with five sensors evenly distributed across the field at a distance. Each node group can collect air temperature and humidity, soil temperature and soil moisture. This article is collected every 30 minutes from 9 am to 2 pm. A portion of the collected data is displayed in Table 2:

Table 2. Some sensors collect data

Type of data	Sensor 1	Sensor 2	Sensor3
Air temperature	22.35	23.34	22.66
Air humidity	77.36	77.65	75.43
Soil temperature	22.48	24.31	23.43
Soil moisture	24.36	23.97	24.04

Among them, the sensor mainly collects four kinds of data, namely air temperature, air humidity, soil temperature and soil humidity.

Meanwhile, to evaluate the application effect of the ECO monitoring system, a control experiment is set up. In this paper, two adjacent fields A and B with basically the same conditions are selected, and the crops are both rice. Field A uses IoT-assisted ECO monitoring system to accurately monitor the environment and crop growth process. Field B is managed using traditional methods and its related data are recorded. Part of the data is displayed in Table 3:

Table 3. Partial data of the control experiment

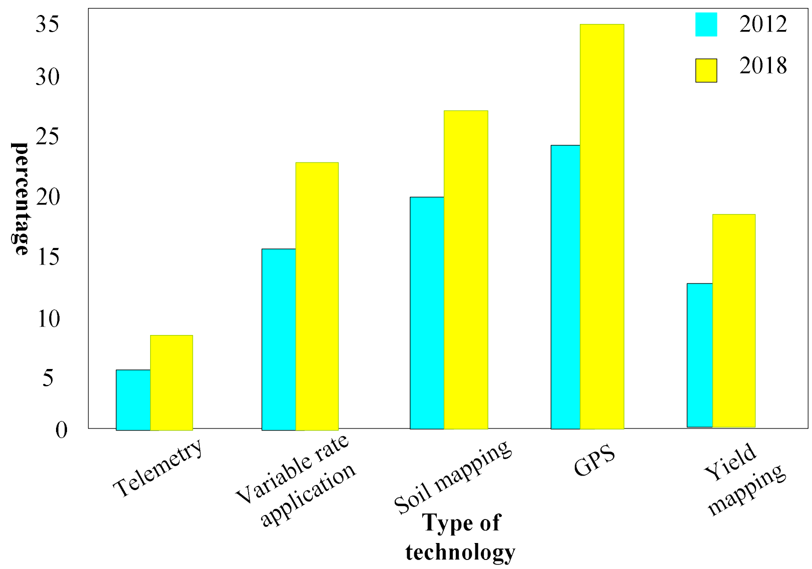
Data item	field A	field B
Occurrence of pests and diseases (January)	1	1
Pesticide usage (January)	37.36	54.23
Occurrence of pests and diseases (February)	1	2
Pesticide usage (February)	40.17	58.66

The data content includes the occurrence of pests and diseases and the use of pesticides, and the number of pests and diseases and the amount of pesticides used are recorded every month. The duration is 1 year, and the test effect is analyzed after arranging the data.

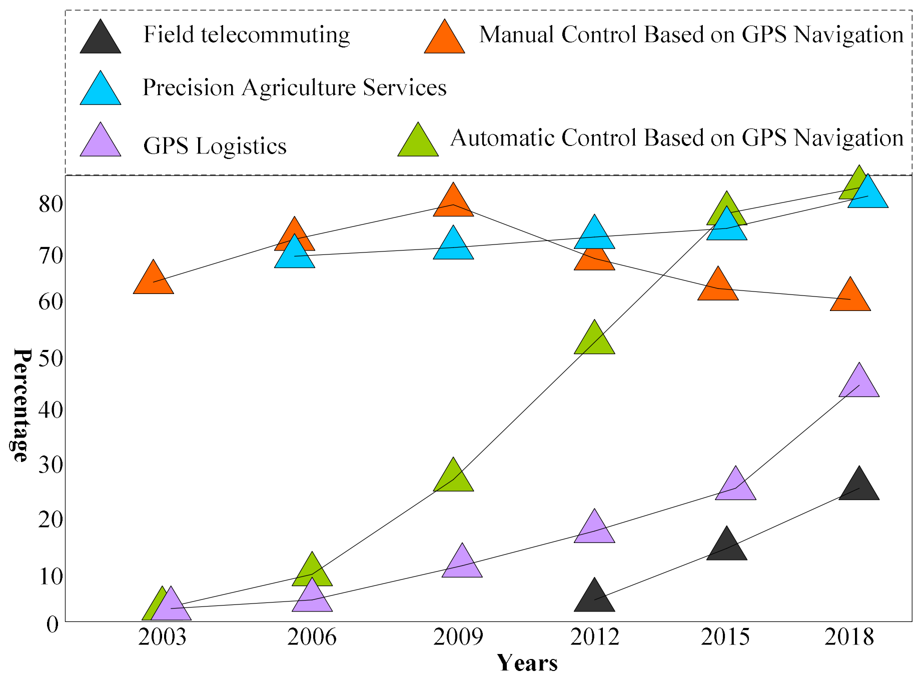
4. Results and Discussion of Development of ECO with Rural Characteristics

4.1. Application Status of Agricultural Modern Technology

Accelerating the development of agricultural machinery informatization and promoting the integration of agricultural machinery informatization and modern technology has become an important trend in the world's agricultural development. This paper conducts a data survey on the status quo of agricultural modernization, and obtains specific results as shown in Figure 5:



(a) Percentage of farmers using modern technology



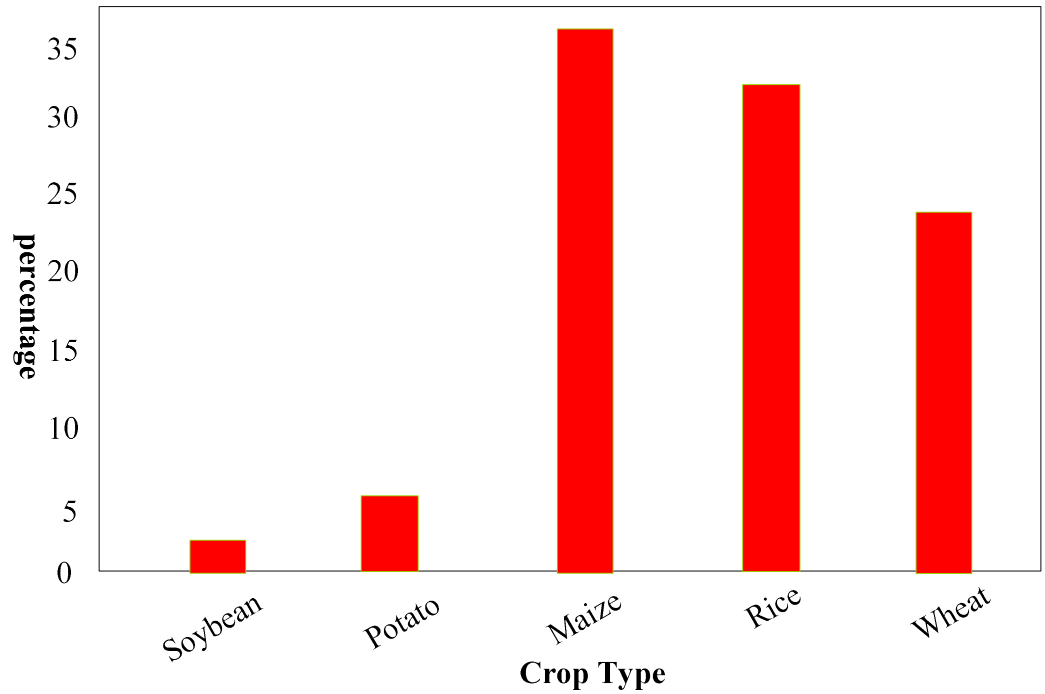
(b) IoT technology application trends

Fig. 5. Status Quo of Modern Agriculture Development

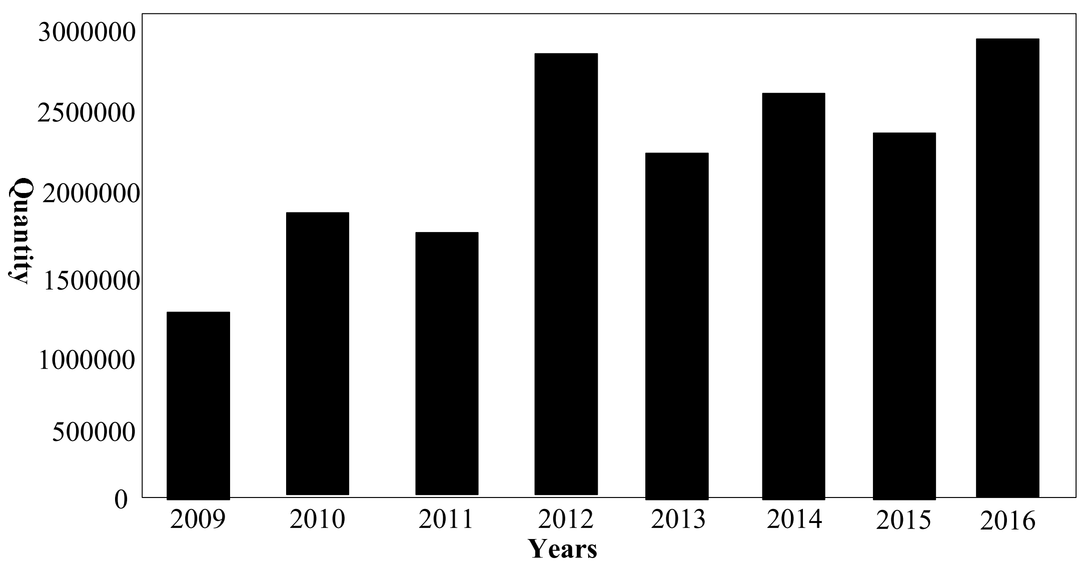
Figure 5 shows the current development of modern agriculture. Figure 5(a) shows the change in the proportion of farmers using modern technology from 2012 to 2018. It can be learned that the proportion of farmers using modern technology is increasing with the development of modern agricultural technology. According to statistics, in 2012, the proportion of farmers who used telemetry technology accounted for 5.04%, and in 2018, it accounted for 8.66%, an increase of 3.62%. In 2012, the proportion of farmers who used variable interest rate application technology accounted for 14.47%, and in 2018, it accounted for 23.68%, an increase of 9.21%. Farmers who adopted soil mapping technology accounted for 18.31% in 2012, and reached 26.33% in 2018, an increase of 8.02%. 24.16% of farmers had started to use global positioning system (GPS) technology in 2012, and by 2018, the proportion reached 34.37%, an increase of 10.21%. In 2012, the proportion of farmers who used yield mapping technology reached 13.43%, and in 2018, the proportion reached 18.06%, an increase of 4.63%. It can be seen that more and more attention has been paid to the application of modern technology in agriculture. Figure 5(b) shows the application trend in modern agricultural technology. According to statistics, in 2003, 63.14% of farmers were using GPS-based manual control technology, which is the most important modern technology used by farmers. At the same time, a small number of farmers used GPS-based automatic control technology and GPS logistics technology, accounting for 4.34% and 5.06% respectively. In 2006, the number of farmers using modern technology increased. At the same time, the vigorously promoted precision agriculture service was well applied, and the proportion of farmers who used it reached 67.36%. In 2009, the proportion of farmers using GPS-based manual control technology reached 77.63%. 61.42% of farmers use precision agriculture services, 11.36% use GPS logistics technology, and 23.43% use GPS-based automatic control technology. In 2012, the number of farmers using GPS-based automatic control technology increased sharply, from 23.43% in 2009 to 52.36%, an increase of 28.93%. At the same time, the number of farmers who use manual control technology has decreased, and the proportion has dropped from 77.63% in 2009 to 63.68%, a decrease of 13.95%. There is still a steady upward trend in farmers using other technologies. A small number of farmers using the emerging field remote office technology appeared, accounting for only 6.36%. In 2015, except that the proportion of farmers using GPS-based manual control technology dropped to 59.67%, the proportion of farmers using other technologies was still increasing. By 2018, the proportion of farmers using GPS-based manual control technology dropped to 58.74%, and the proportion of farmers using GPS-based automatic control technology increased to 80.13%. The proportion of farmers using precision agriculture services increased to 78.69%, the proportion of farmers using GPS logistics technology increased to 45.62%, and the proportion of farmers using field remote office technology increased to 25.66%. It can be learned that the number of farmers using modern agricultural technology is increasing, and they tend to develop in automation, precision, and remoteness.

4.2. Demand of Rural Characteristic ECO Information Monitoring

China is a large agricultural producer and a country prone to crop diseases and pests. In recent years, due to unfavorable factors such as global warming, frequent occurrence of abnormal weather between countries and regions, active economic and trade activities, and harsh ecological environment, the areas and degrees of damage to pests have increased year by year. In this paper, data analysis is carried out on the loss of food pests and pesticides in China in recent years. The results are shown in Figure 6:



(a) Proportion of China's food pests and diseases loss in 2016



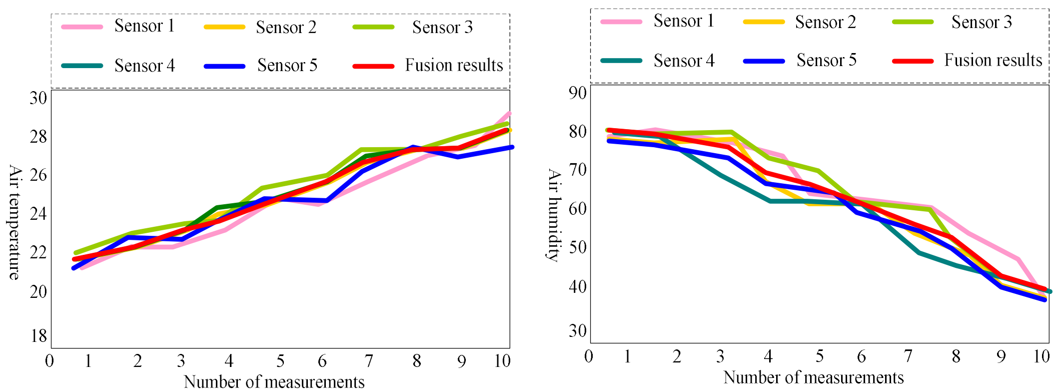
(b) Pesticide consumption

Fig. 6. Loss of food pests and pesticides consumption

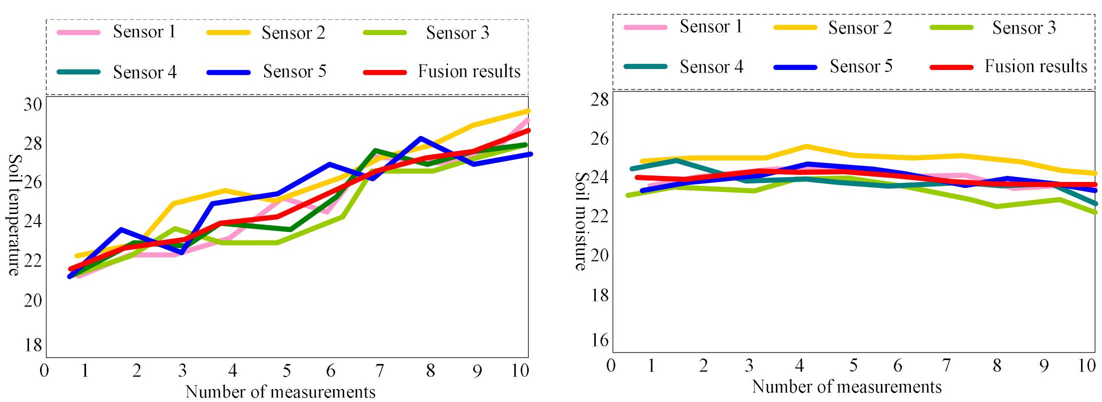
Figure 6 shows the loss of pest damage and the use of pesticides in China. Figure 6(a) shows the proportion of five major food crops lost to pests and diseases in China in 2016. According to statistics, soybeans accounted for 3.26%, potatoes accounted for 5.66%, corn accounted for 35.34%, rice accounted for 31.67%, and wheat accounted for 24.07%. Figure 6(b) shows the situation of pesticides used to control food pests and diseases from 2009 to 2016. According to statistics, the consumption of pesticides in 2009 was about 1.4623 million tons, the consumption of pesticides in 2010 was about 1.7863 million tons, and the consumption of pesticides in 2011 was about 1.7714 million tons. In 2012, the consumption of pesticides reached about 2.7325 million tons, in 2013 it was about 2.1633 million tons, in 2014 it was about 2.5331 million tons, and in 2015 it was about 2.3867 million tons. In 2016, the consumption of pesticides reached about 2.8423 million tons. On the one hand, it is urgent to carry out effective control of pests and diseases through accurate monitoring of fields to reduce losses. On the other hand, accurate monitoring of field information can effectively control the dosage of pesticides, reduce pesticide residues, and improve food safety and quality.

4.3. Monitoring System Multi-sensor Data Fusion Test

To verify the effect of data fusion, a comparative experiment of field information monitoring data is carried out in this paper. The experimental site is an agricultural greenhouse. During the experiment, five sensors were evenly distributed on the farmland at a distance. Each node group can collect air temperature and humidity, soil temperature and humidity. This paper collects sampling data every 30 minutes from 9:00 am to 2:00 pm. The collected data are fused and compared to obtain specific results as shown in Figure 7:



(a) Air temperature and humidity monitoring data and fusion results



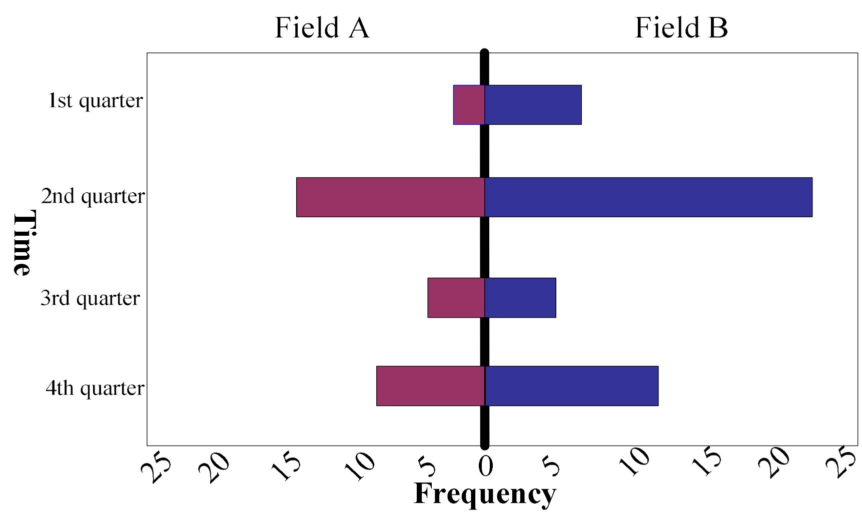
(b) Soil temperature and humidity monitoring data and fusion results

Fig. 7. Multi-sensor data fusion test results

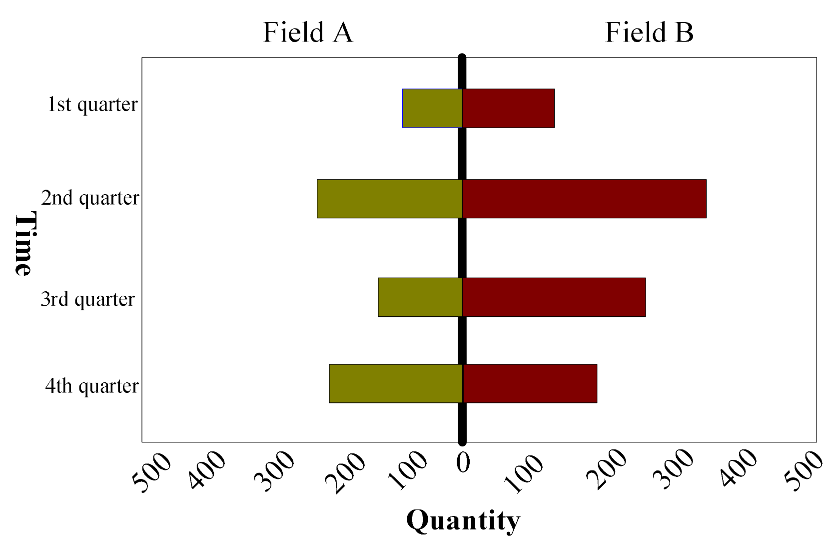
Figure 7 shows the results of the multi-sensor data fusion test. In this paper, the actual test values obtained by measuring the same parameters by each sensor are compared with the results after data fusion. Figure 7(a) shows the monitoring data and fusion results of the air temperature and humidity in the greenhouse by five sensors. Figure 7(b) shows the monitoring data and fusion results of soil temperature and humidity in the greenhouse by five sensors. It can be learned from the figure that the data fusion effect is good, which can meet the requirements of multi-sensor data fusion in field detection, and improve the accuracy of detection data.

4.4. Comparative Experiment of Monitoring System Application Effect

This paper sets up a controlled experiment to evaluate the application effect of the ECO monitoring system. In this paper, two adjacent fields A and B with basically the same conditions are selected, and the crops are both rice. Field A uses IoT-assisted ECO monitoring system to accurately monitor the environment and crop growth process. Field B is managed using traditional methods. The duration of the experiment is one year. According to the occurrence of diseases and insect pests and the use of pesticides, the frequency of occurrence of diseases and insect pests and the number of pesticides used are recorded every month, and finally the recorded data are compared and analyzed. The specific results are illustrated in Figure 8:



(a) Frequency of occurrence of pests and diseases



(b) Quantity of pesticides used

Fig. 8. Occurrence times of pests and pesticides in different fields

As shown in Figure 8, the number of plant diseases and insect pests and the use of pesticides in different fields in four seasons were recorded. Figure 8(a) shows the occurrence times of pests and diseases in four seasons of field A and field B. It can be seen that the incidence of diseases and insect pests in field A is significantly less than that in field B as a whole. According to statistics, the second quarter is a period of high incidence of pests and diseases, with 14 occurrences of pests and diseases in field A, and 21 occurrences of pests and diseases in field B. A total of 31 pests and diseases occurred in field A, and 45 pests and diseases occurred in field B in one year. Field A was 31.11% lower than field B in terms of the frequency of pests and diseases. Figure 8(b) shows pesticide use in two fields over four seasons. According to statistics, a total of 760.33 kg of pesticides were used in field A, and a total of 901.82 kg of pesticides were used in field B. In contrast, field A was 15.69% lower than field B in terms of the amount of pesticides used. It can be seen that the use of IoT-assisted field monitoring system to accurately monitor agricultural fields can effectively reduce the occurrence of pests and diseases and reduce the amount of pesticides used.

5. Conclusion

Modern agricultural science and technology continues to develop under the era of intelligent transformation of agriculture more and more intense, and people for the rural characteristics of ECO requirements are increasingly high. The development of rural characteristic ECO cannot be separated from the contribution of IoT. IoT has been used in the rural characteristic ECO development due to its powerful data monitoring capability. Through comprehensive experimental tests, it can be seen that the IoT-based multi-sensor data fusion algorithm can accurately fuse the data of air temperature and humidity, soil temperature and humidity monitored on site. This satisfies the monitoring system's need for monitoring data accuracy. Through the analysis of the results of field control experiments with different management methods, the occurrence of pests and diseases in field A using the IoT-assisted field information monitoring system was significantly less than that in field B in the four seasons, which was 31.11% lower than that in field B. In terms of the use of pesticides, the amount of pesticides used in field A is less than that in field B, and the amount of pesticides used in field A is 15.69% lower than that in field B. This reduces the incidence of pests and diseases and the use of pesticides. It can be seen that the IoT-assisted field information monitoring system provides strong support for the improvement of the development level of rural characteristic ECO.

Funding

This work was supported by Inner Mongolia Autonomous Region Nature Fund Project: "Research on Ecosystem Service Evaluation and Trade-off Collaborative Impact Mechanism in Key Ecological Functional Areas of Inner Mongolia" (2023MS07004).

Reference

[1] Hu, X., Sun, L., Zhou, Y., & Ruan, J. (2020). Review of operational management in intelligent agriculture based on the Internet of Things. Frontiers of Engineering Management, 7(3), 309-322.

[2] Ray, P. P. (2017). Internet of things for smart agriculture: Technologies, practices and future direction. Journal of Ambient Intelligence and Smart Environments, 9(4), 395-420.

[3] Mowla, M. N., Mowla, N., Shah, A. S., Rabie, K., & Shongwe, T. (2023). Internet of things and wireless sensor networks for smart agriculture applications-a survey. IEEE Access.

[4] Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. N. (2018). An overview of Internet of

Things (IoT) and data analytics in agriculture: Benefits and challenges. IEEE Internet of things Journal, 5(5), 3758-3773.

[5] Mohammadian, A., Heidaridehooie, J., & Qorbani, A. (2020). Prioritizing the applications of internet of things in the agriculture by using sustainable development indicators. Iranian Journal of Agricultural Economics and Development Research, 51(4), 745-759.

[6] Wang, Y., Zhang, P., & Gu, X. (2024). The evolution of ecological agriculture: Technological innovations, environmental impact, and future challenges. Advances in Resources Research, 4(4), 792-805.

[7] Jararweh, Y., Fatima, S., Jarrah, M., & AlZu'bi, S. (2023). Smart and sustainable agriculture: Fundamentals, enabling technologies, and future directions. Computers and Electrical Engineering, 110, 108799.

[8] Tzounis, A., Katsoulas, N., Bartzanas, T., & Kittas, C. (2017). Internet of Things in agriculture, recent advances and future challenges. Biosystems engineering, 164, 31-48.

[9] Sun, Y. (2019). Remote Monitoring Method of Eco-agricultural Soil Environment Based on Internet of Things. Ekoloji Dergisi, (108).

[10] Salam, A. (2024). Internet of things in agricultural innovation and security. In Internet of Things for Sustainable Community Development: Wireless Communications, Sensing, and Systems (pp. 71-112). Cham: Springer International Publishing.

[11] Shi, X., An, X., Zhao, Q., Liu, H., Xia, L., Sun, X., & Guo, Y. (2019). State-of-the-art internet of things in protected agriculture. Sensors, 19(8), 1833.

[12] Mulenga, R., Kalezhi, J., Musonda, S. K., & Silavwe, S. (2018, June). Applying Internet of Things in monitoring and control of an irrigation system for sustainable agriculture for small-scale farmers in rural communities. In 2018 IEEE PES/IAS PowerAfrica (pp. 1-9). IEEE.

[13] Wu, F., & Ma, J. (2020). Evolution dynamics of agricultural internet of things technology promotion and adoption in China. Discrete Dynamics in Nature and Society, 2020(1), 1854193.

[14] Shaikh, F. K., Karim, S., Zeadally, S., & Nebhen, J. (2022). Recent trends in internet-of-things-enabled sensor technologies for smart agriculture. IEEE Internet of Things Journal, 9(23), 23583-23598.

[15] Khan, T. (2020). Internet of things: the potentialities for sustainable agriculture. International Business, Trade and Institutional Sustainability, 291-302.

[16] Maksimovic, M. (2018). Greening the future: Green Internet of Things (G-IoT) as a key technological enabler of sustainable development. Internet of things and big data analytics toward next-generation intelligence, 283-313.

[17] Nag, A., Das, A., Chand, N., & Roy, N. (2024). Sustainable agriculture: a critical analysis of internet of things—based solutions. In Intelligent Systems and Industrial Internet of Things for Sustainable Development (pp. 118-138). Chapman and Hall/CRC.

[18] Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E. H. M. (2019). Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. IEEE access, 7, 129551-129583.

[19] Liu, S., Guo, L., Webb, H., Ya, X., & Chang, X. (2019). Internet of Things monitoring system of modern eco-agriculture based on cloud computing. Ieee Access, 7, 37050-37058.

[20] Zhu, Z., Bai, Y., Dai, W., Liu, D., & Hu, Y. (2021). Quality of e-commerce agricultural products and the safety of the ecological environment of the origin based on 5G Internet of Things technology. Environmental Technology & Innovation, 22, 101462.

[21] Chen, J., & Yang, A. (2019). Intelligent agriculture and its key technologies based on internet of things architecture. IEEE Access, 7, 77134-77141.

[22] Neményi, M., Kovács, A. J., Oláh, J., Popp, J., Erdei, E., Harsányi, E., ... & Nyéki, A. (2022). Challenges of sustainable agricultural development with special regard to Internet of Things: Survey. Progress in Agricultural Engineering Sciences, 18(1), 95-114.

[23] Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. Agriculture, 12(10), 1745.

[24] Neményi, M., Ambrus, B., Teschner, G., Alahmad, T., Nyéki, A., & Kovács, A. J. (2023). Challenges of ecocentric sustainable development in agriculture with special regard to the internet of things (IoT), an ICT perspective. Progress in Agricultural Engineering Sciences, 19(1), 113-122.