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Agricultural Environmental Data Monitoring and Control System Based on Internet of Things

Qiudong Yu

College of Water Resources & Civil Engineering, China Agricultural University, Beijing 100083, China
Department of Computer and Information Engineering, Tianjin Agriculture University, Tianjin 300384, China

Guanghui Teng*

College of Water Resources & Civil Engineering, China Agricultural University, Beijing 100083, China
**Corresponding Email: futong@cau.edu.cn*

Abstract
As a third tide of the information industry, Internet of Things can solve a series of scientific and technological problems, such as acquisition of information distributed in an extensive space, efficient and reliable information transmission and smart decision-making for various applications. It will be a booster and accelerator to realize the transformation from the traditional agriculture to the modern agriculture. During the agricultural production process, various agricultural factors, including temperature, moisture, illumination intensity, CO2 concentration, moisture and other nutrients, jointly influence the growth of drops. The management style of the traditional agriculture has been far from meeting standards of fine management, but still remains an extensive one. Under the latter management style, it is humans' perception that manages the above environmental parameters, which might not be accurate enough. Therefore, in order to achieve smart management of the modern agriculture, it is necessary to build a practical and reliable agricultural environment monitoring system capable of long-term monitoring. In this paper a smart agriculture monitoring system based on Things of Internet is built. The system can accurately and immediately obtain the growth environment information of crops and conduct remote monitoring of the information.
Key words: INTERNET OF THINGS, SMART AGRICULTURAL, DATA MONITORING, CLOUD COMPUTING

1. Introduction

Information treatment system is made up of three parts, namely input, output and treatment [1]. Its major missions include information storage, processing, transformation, retrieval and application [2]. Information treatment system can be divided into information storage and retrieval system, monitoring control information system and process control system [3]. In the broad sense, various single chip microcomputers, PLCs and other information treatment devices which can conduct logical operations also belong to the scope of information treatment system [4]. As a simple computer system, it can calculate the acquired information and give feedback to the performing mechanism. Small-scale or single-span greenhouses often use information treatment systems of the kind [5].

In the agricultural Internet of Things system, the information treatment system first handles the information acquired by the agricultural sensor and gives decision-making feedback. In the current agricultural Internet of Things technical system, the most-discussed and more advanced information treatment system is the cloud computing system [6].

The development of the cloud computing technology provides favorable solution plans for the remote management system [7]. Various cloud computing manufacturers, including Amazon, IBM, Google, Microsoft, Sun and so on, have launched their self-developed cloud computing platforms. At the initial development stage, the cloud computing system featured data centers to achieve data storage and management [8]. However, at the advanced development stage, to achieve extensive service of the Internet, to build a large-scale professional Internet application platform, to integrate the core software and hardware platform of the information treatment system and to provide services for multiple terminals are more important [9].

2. Monitoring node software design

In the agriculture\al Internet of Things, after information acquired by various environment sensors is treated [10], the feedback instructions should control environment adjustment devices through various controllers, computers and other controlling devices [11]. The greenhouse control system can be divided into the manual control system and the automatic control system according to different control modes [12]. The latter can be further divided into the digital director controlling system, the controller controlling system and the computer controlling system [13].

The agriculture environment monitoring system refers to the idea of hierarchical design, and divides the whole built-in system into the bottom driving layer, the middle service layer and the bottom application layer. The bottom driving layer is mainly used to realize SPI, I2C, USART, GPIO and other interfaces of the kind. uCOS transplanting can also be realized in the bottom driving layer. The middle service layer is to actuate the driving programs of specific chips, and provide API for the bottom application layer. The middle service layer includes uCOS core codes and FrccMODBUS communication function [14]. The top application layer assigns specific tasks according to the on-site agricultural environment monitoring situation. These tasks include communication through MODBUS, detection through the sensor, controlling or alarming through the actuator, etc. The function of the top application layer can directly invoke the PI function of the bottom driving layer and the middle service layer, or invoke the delayed function and the task data sharing function of the uCOS software. The built-in software structure of the agricultural environment monitoring nodes is shown in Figure. 1.

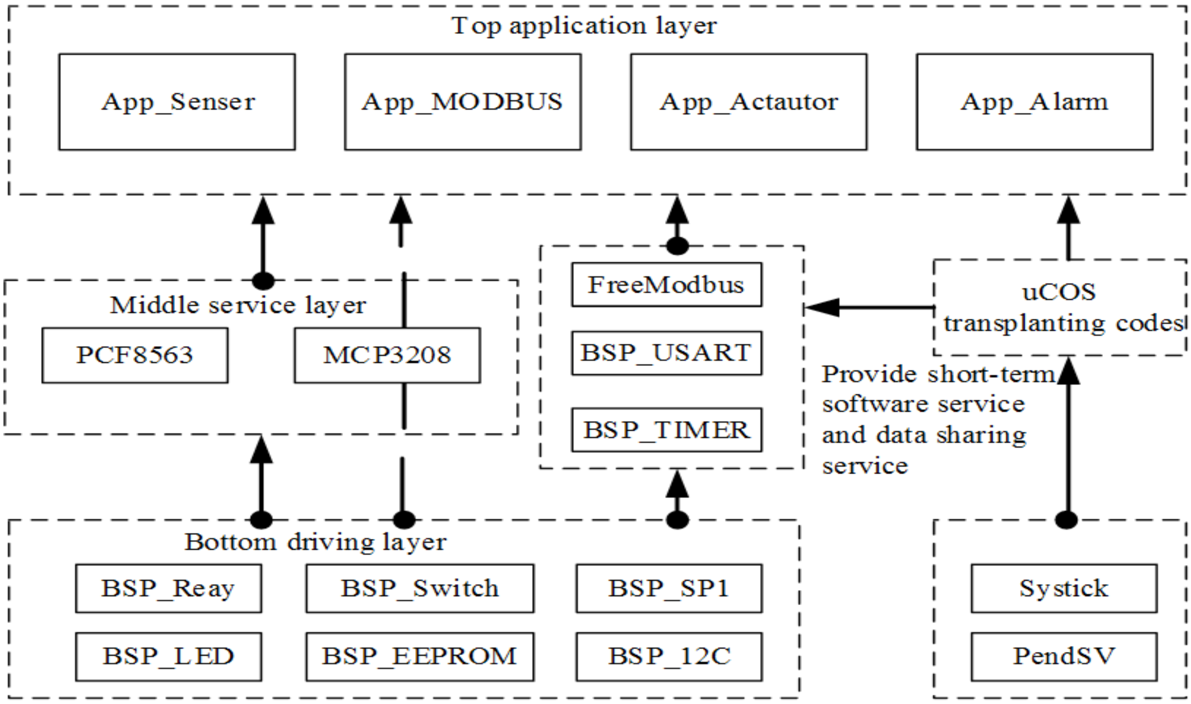

Figure 1. Built-in software structure of the agricultural environment monitoring nodes

The bottom driving mainly includes the corresponding driving function of STM32 for different purposes. Company ST has provided a complete function base for the development of STM32, allowing uses to achieve most functions without o\the operation register. The major mission of the bottom driving layer is to shield as much hardware information of the built-in system as possible based on the STM32 function base. For example, when several LEDs are operated, relevant GPIO interfaces are not operated directly. Instead, relevant functions are packaged in BSP_LED source document. The source document contains the initialized codes of the relevant IO interface of LEDs. The initialized codes are invoked together during the initialization of hardware. Code all LEDs. The opening and close function of LEDs is guided by the same API function. During invocation, only the serial number of the LED should be provided. API function will control the corresponding GPIO terminal according to the serial number. When the hardware at the bottom layer undergoes changes, the codes of the middle service layer and the bottom application layer will not be influenced. The hierarchical design brings greater convenience to software update.

The bottom driving layer also includes the transplanting of relevant parts of uCOS and CPU. Transplanting and use of uCOS is a relatively complex process. Generally speaking, transplanting of uCOS can be divided into two parts on STM32. One is the Systick modification part and the other is the PcndSV modification part. In essence, both Systick and PcndSV are Cortex M3 core interruption. Systick interruption provides the basic timing service for uCOS. It updates the system clock of uCOS by invoking OSTimeTick function. The context during the mission exchange is saved when PendS is abnormally interrupted. PendSV is made up of the assembly codes. Its major function is to press special function register and program status register into the stack, and automatically pop up the stack on return.

The design idea of the middle service layer is similar to that of the bottom driving layer. The middle driving layer provides the API function for the top application layer to enable the latter to achieve certain function through invoking certain API function and inputting the fewest parameters. For example, during the design of the MCP3208 middle service layer, the MCP3208 invokes relevant API function of SPI in the bottom driving layer. In the middle service layer, MCP3208 has two important API functions. One is MCP3208.Congif function, which is mainly responsible for the initialized function of MCP3208. The function is invoked during the system initialization. However, the other function is MCP3208_GetADValue. The input parameters of the function only have the communication channel. The middle service layer can invoke the API function to obtain AD transformation results. However, the bottom application layer has no need to pay attention to the actuating process of MCP3208. The middle driving layer also includes FreeMODBUS, which is used to achieve the node built-in system and the important parts of the ZigBee module communication. This part will be further expounded in the transmission layer design of the environment monitoring system.

The top application layer materializes the functions of the environment monitoring nodes or actuating nodes. Every mission is based on that of the uCOS built-in operation system. The adoption of the mechanism makes every mission like the thread in the computer. Multiple tasks can be coordinated to operate and occupy the CPU through time sharing so as to make full use of the operation efficiency of STM32. To put it specifically, App_MODBUS provides the communication service for MODBUS. The mission achieves communication through USART and ZigBee module. It acquires relevant instruction from the information aggregation calculation through the MODBUS mechanism, and returns the treatment results. The mission design in the transmission layer will be further expounded. App_Sensor detects mission for the sensor. The mission collects the detection value of the senor at interval. The detected value will undergo software filtering and be saved. App_Actuator drives the mission for the actuator. The mission controls the relay or MOSFET through MODBUS instructions to drive the actuating devices. App_Alarm is the alarm mission. By analyzing the upper or lower limit of the sensor, the function along with the set value judges whether the sensor is at a normal state. If it is abnormal, the zone bit should be changed correspondingly. In the top application level, there is several data sharing. In the uCOS system, data sharing can be achieved through the close and open of the global interruption or the use of the message mailbox.

3. Data transmission

Efficient data transmission is the ultimate goal of network program development. In the system, data transmission undergoes the following four steps from the moment of being collected to the moment of being uploaded to the upper computer.

3.1 Data sending in terminal node

After the terminal node collects data and conducts integration of the data, the data will be sent out. During data sending, the frame data is built according to the frame form stipulated in the agreement. The frame data include the frame header and the frame content. The former consists of the frame type, the source address, the objective address, PAN, CLUSTERID, etc. The latter consists of the environmental parameters and the battery voltage value. Then, the channel is monitored. If the channel is found to be empty, SPI bus will be immediately launched to send data. The flow of data sending in terminal node is shown in Figure 2.

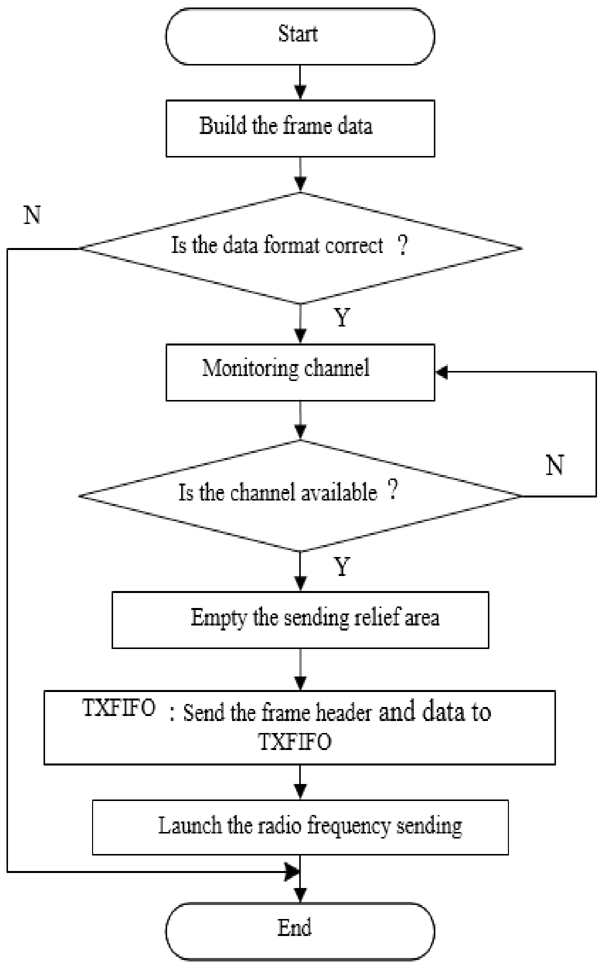

Figure 2. Flow of data sending in terminal node

3.2 Data transmission in routing node

When the routing node receives a data packet, the data packet should first goes through the analysis of the MAC layer and the NWK layer to determine the destination of the packet. The destination obtained through analysis can decide the next operation of the routing node. If the destination coincides with the location of the routing node, the routing node will unpack the data packet to conduct data treatment. Otherwise, the current function of the routing node is to forward data. The routing node should analyze the node location of the next hop, and send the data to the node location of the next hop. The flow of data transmission in routing node is shown in Figure 3.

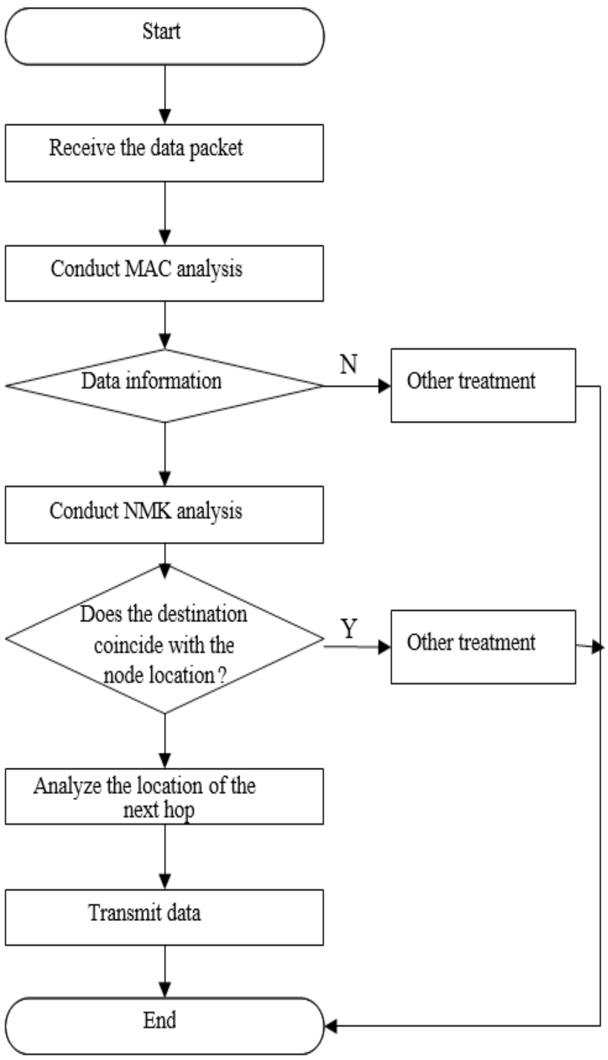

Figure 3. Flow of information transmission in routing node

3.3 Data receiving in coordinate node

The network layer of the ZigBee coordinator node or routing node must ensure the receiving machine is always on. After the coordinator node receives data, SFD will be triggered and the pin will turn from the low level to the high level, thus triggering IRQ interruption. The interrupt service routine will invoke relevant function to be responsible for data treatment. After treatment, the data will be submitted to the MAC layer of the ZigBee protocol stack for further treatment. The flow of data receiving in coordinator node is shown in Figure 4.

3.4 Data uploaded by the coordinator node to the upper computer

The coordinator node interacts with the data and control indexes through UART and the upper computer. After the start of the interactive program, the coordinator first initialize the UART: Enable UART, clarify the start bit, the stop bit, the parity check bit and the flow control type; open the receiving and sending interruption of UART to set the data length and the data communication Baud rate. After the completion of initialization, when there are data receiving and sending tasks, the coordinator node can implement the interrupt service routine accordingly, and send the data to the upper computer or receive the control instruction from the upper computer. The interaction flow of data and control instructions between the coordinator node and the upper computer through UART is shown in Figure 5.

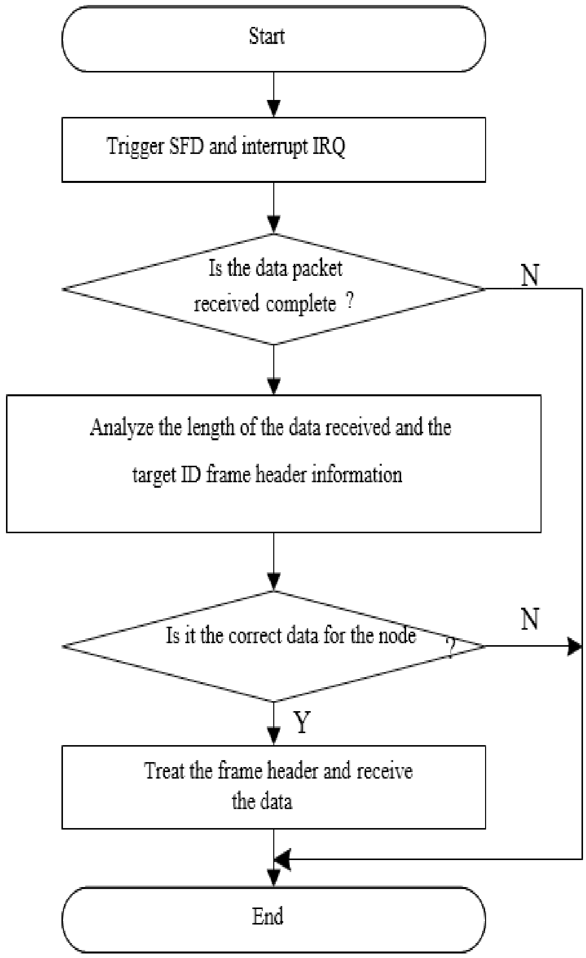

Figure 4. Flow of data receiving in coordinator node

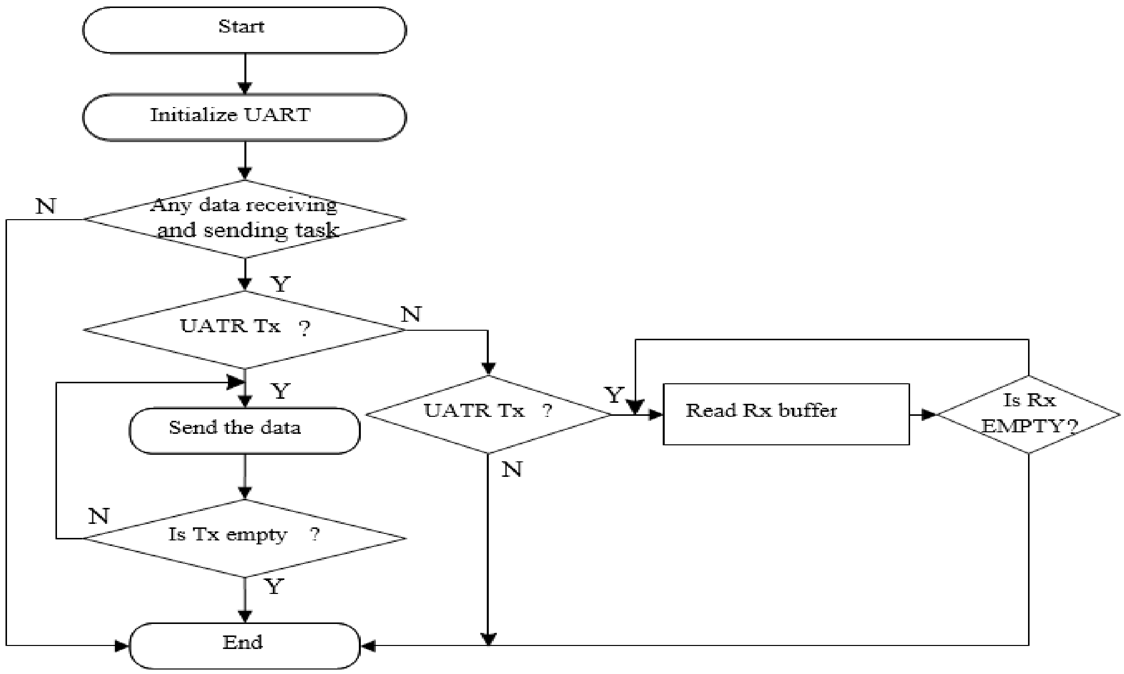

Figure 5. Flow of data receiving and sending UART

4. Data pre-treatment

There have been ten groups of environment information undergoing the isomerous data integrated treatment and the analysis data for experts' monito- ring and judgment of indexes acquired from the agricultural database. (See Table 1) Since both the environment information and the analysis data are discrete, discretization is conducted. The discrete grades and indexes classification of the analysis data are shown in Table 2. The analysis data after pre-treatment are shown in Table 3.

Table 1. Agricultural database

Serial No.	Precipitation (P/mm)	CO2 concentration (C/%)	Humidity information (H/%)	Humidity information (T/°C)	Monitoring result (R)
1	85.2	15.9	31.2	1.3	98
2	149.2	17.5	33.2	-0.9	131
3	169.8	14.1	72.8	-0.8	231
4	229.1	15.2	26.8	1.4	255
5	307.5	14.5	97.5	-0.8	285
6	234.5	15.8	30.9	1.5	136
7	73.3	16.2	30.1	3.9	39
8	12.2	17.8	27.5	2.8	199
9	94.5	16.3	3.6	3.9	103
10	151	15.8	16.6	-0.2	411

Table 2. Discretion grade of the analysis data

Grade	Precipitation (P/mm)	CO2 concentration (C/%)	Humidity information (H/%)	Humidity information (T/ ˚C)	Monitoring result (R)
1	<100.0	<14.8	<25.0	<0.1	<131
2	100.0~160.0	14.8~15.5	25.0~40.0	0.1~1.5	132~2224
3	160.1~250.0	15.6~16.0	40.1~75.0	1.6~3.0	225~317
4	>250.0	>16.0	>75.0	>3.0	>317

Table 3. Analysis data after pre-treatment

Grade	Precipitation (P/mm)	CO2 concentration (C/%)	Humidity information (H/%)	Humidity information (T/ ˚C)	Monitoring result (R)
1	P1	C4	H2	T2	R1
2	P2	C4	H2	T1	R2
3	P3	Cl	H3	T	R3
4	P3	C2	H2	T2	R3
5	P4	Cl	H4	T1	R3
6	P3	C3	H2	T2	R2
7	P1	C3	H2	T4	R1
8	P1	C4	H2	T3	R2
9	P1	C4	H1	T4	R1
10	P2	C4	H1	T1	R4

4.1. Association rule mining based on Apriori

It is assumed that the minimum support threshold value, min_sup=20%; the minimum confidence threshold value, min_conf=60%. According to the writing program of Apriori algorithm, the analysis data after pre-treatment based on Table 4 are searched so as to meet the association rule of the minimum support threshold value and the minimum confidence threshold value. As is shown in Table 4, the left of these association rules stands for the set of the grade value that different environment information is corresponding to. The right stands for the grade value to which the monitoring results are corresponding to. For example, the association rule, "C1T1⇒R3," can be interpreted as "when CO2 concentration and temperature information both belong to Grade 1, the monitoring results belong to Grade 3."

Table 4. Association rule mining results

Association rule	Support degree (/%)	Confidence degree (/%)
P1⇒RI	30	76
P3⇒R3	20	66.8
C1⇒R3	20	100
T4⇒R1	20	100
P1C4⇒R1	20	66.8
PIH2⇒RI	20	66.8
P1T4⇒R1	20	100
C1T1⇒R3	20	100
C4H2⇒R2	20	66.8

4.2. Information integration based on the fuzzy reasoning

Confirm the membership function of different environment information and monitoring results according to the discretion grade of the analysis data in Table 2. Adopt the triangle membership function to ensure the instantaneity and rapidness of information integration based on the fuzzy reasoning. The membership function of different environment information and monitoring results is shown in Fig. 3. The association rule mining results in Table 4 can be transformed into the corresponding fuzzy rule. If the association rule "C1T1⇒R3" can be interpreted as "when CO2 concentration and temperature information belongs to Grade 1, the test results belong to Grade 3." The fuzzy rule can be expressed as: If(C is Cl)and(T is TI)then(R is R3).

Finally, MATLAB language programming is employed to achieve multi-environment monitoring and judgment simulation research based on the fuzzy reasoning information integration; Function ADDVAR is employed to define the input and output variable of different environment information based on the fuzzy reasoning information integration; Function ADDMF is employed to define the membership function of the input and output variable of the fuzzy reasoning system; Function RULELIST and Function ADDRULE are employed to define the fuzzy rules of the fuzzy reasoning system, Besides, Function SHOWRULE can be employed to check the fuzzy rules of the fuzzy reasoning system; Function FUZZY can be employed to invoke the graphical user interface of the fuzzy reasoning system and check the fuzzy reasoning process schematic diagram so as to control information integration and conduct decision-making simulation.

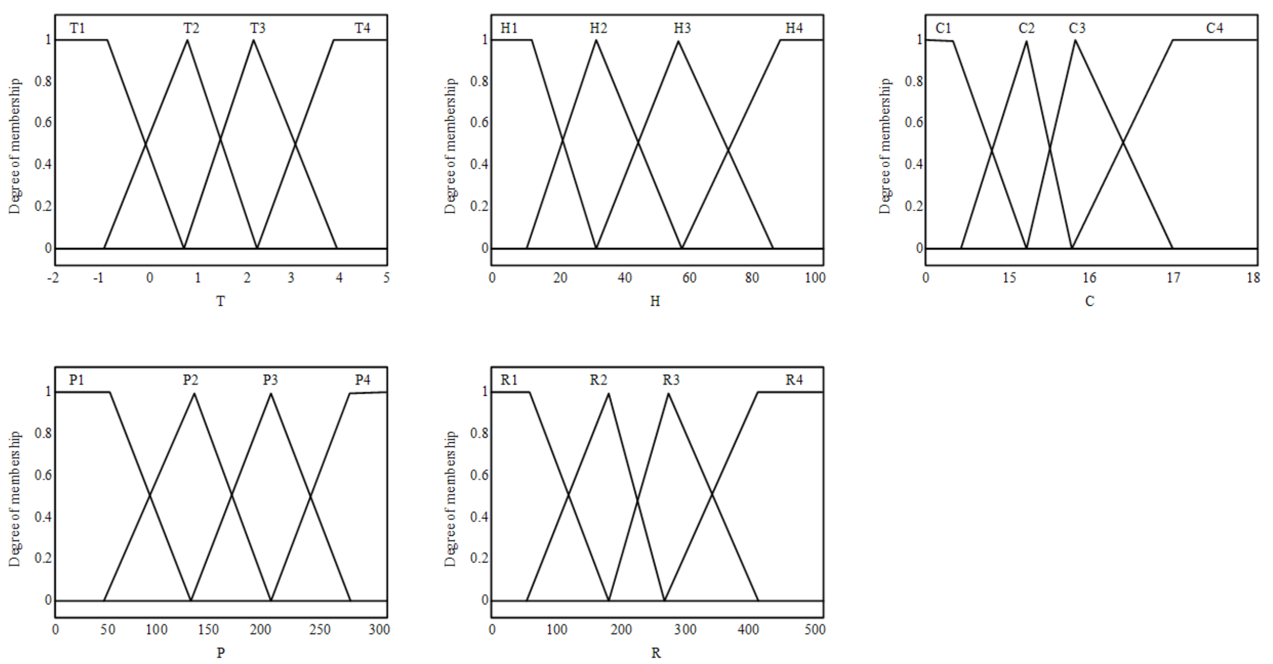

Figure 4. Membership function of different environment information and test results

Up to now, the fuzzy monitoring and judgment system based on the multi-environment information integration has been designed. Through the command window, Function EVALFIS is employed to conduct real-time simulation. The actually monitored results and the information integration results obtained through simulation are compared. (See Table 5) From Table 5, it can be seen that only one data group of five show great deviations, registering an accuracy rate of being higher than 80%.

Table 5. Comparison between the actually measured results and the information integration results

Serial No.	Precipitation (P/mm)	CO2 concentration (C/%)	Humidity information (H/%)	Humidity information (T/ ˚C)	Monitoring result (R)	Information integration results (R)'
11	87.0	17.3	21.1	-0.6	L30E1	117.5231E1
12	84.0	17.2	2.12	3.5	128EI	71.5465E1
13	124.7	17.7	1.6	23	223E2	87.6593E1
14	234.0	14.6	32.6	1.5	312E3	286.8651E3
15	251.0	14.7	81.1	0.3	267E3	287.4288E3

5. Conclusions

This paper targets at realizing the information integration layer of the multi-environment information integration monitoring and judgment model oriented towards the agricultural Internet of Things. First, the associative rule between different environment information and the monitoring results can be obtained through the Apriori algorithm. Then, the real-time environment information can be input as the fuzzy reasoning information integration. As the rule for the fuzzy reasoning information integration, the associative rule adopts the numerical value obtained through calculation as the monitoring results. At last, corresponding control strategies are formulated based on the monitoring results. The experimental results suggest that the monitoring identification rate of environment by the multi-environment information integration monitoring and judgment model can reach 80%, so the model boasts high agricultural monitoring value and promising application prospects.

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