Design of Water-saving Irrigation Monitoring System Based on CC2430 and Fuzzy-PID

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***Abstract*-In order to solve the problems existing in the traditional water-saving irrigation monitoring such as smaller monitoring area and lower sampling rate, a water-saving irrigation control system based on CC2430 and fuzzy PID control strategy is designed and developed. The system consists of eight sensor nodes, a gateway node and a monitoring center, and uses CC2430 as the core to develop wireless sensor nodes which follow the ZigBee communication protocol, it uses ZigBee technology to achieve networking of wireless sensors and the automatic aggregation of monitoring data, and uses the fuzzy PID control algorithm to achieve the regulation of irrigation water so as to improve the control precision. The functions, such as management of various sensor nodes, management of a large number of environmental data and early warning are achieved based on embedded database. The test results have showed that this system has several advantages such as high reliability in data transmission, stability, adaptability, good openness, economy, and short development cycle, which is suitable for real-time monitoring of agricultural water-saving irrigation.**

Keywords-CC2430; Fuzzy-PID Strategy; Water-saving Irrigation; Monitoring

I. INTRODUCTION

In China the problems existing in agricultural water are on the one hand, the shortage of water resources and serious waste of water resources on the other hand, the average utilization rate of only about 40%, which is far below the level of developed countries. Thus, China's water scarcity is behind a huge water-saving potential. With the development and progress of water-saving irrigation technology, how to develop an irrigation control system suitable for national situations has become a research hotspot [1, 2]. Water and agricultural production are inseparable and with the development of social economy, the requirements for irrigation quality, safety, and reliability are becoming more prominent. Irrigation capability has a direct impact on crop growth and people's needs, thus to ensure a low-cost, reliable and efficient operation of the irrigation equipment become the main direction of technology of improving agricultural systems in recent years [3]. Water-saving irrigation control system is characterized by the large area involved in agricultural irrigation, the complex terrain of control region, numerous and scattered field control points and measurement points, and the effects of line laying on fields mechanization. The traditional water-saving irrigation monitoring system is mainly based on wired communication means [4,5], which results in some problems in the production practice such as complicated wiring, difficult to maintain, and flexible deployment of the sensor node, unable to change with the crop [6]. In recent years, many researchers have applied wireless technology to water-saving irrigation [7-9], but these technologies have their own features, such as high cost and power consumption, and inability to be extended in large-scale applications. Using a wireless sensor network to build the monitoring system has the advantages of low cost, small size, ad hoc networks, etc., which has broad prospect of application in the field of environmental monitoring [10-12].

Aiming at the problems of current water-saving irrigation system, a low-power, low cost, flexible networking, friendly interface and easy to manage water-saving irrigation monitoring system is designed combined with wireless sensor network technology, ZigBee technology, and embedded technology. Through the analysis of the situation on the farm, the use of sensor nodes for data acquisition and wireless transmission technology using fuzzy PID control valves for each water speed, start and stop of the decision-making, intelligent adjustment of irrigation timing and water, improves the control accuracy, thereby greatly improves the irrigation efficiency.

II. OVERALL DESIGN OF SYSTEM

A. *System Requirements Analysis*

Through investigation and analysis, the application requirements of environmental monitoring system include: a) The soil environmental factors such as temperature and humidity are sampled and processed in real-time and stored in the database for the management to query for 24h online; b) The collected data are real-time transmitted and aggregated by low-cost, low-power wireless communication mode to provide diagnosis and overrun alarm for management to make decision; c) the detection information is processed, which provides administrators with an intuitive system management platform, that is, completing sensor management, environmental information processing, storage and analysis capabilities, and according to the predetermined control strategy, control output is formatted, which can be directly applied in the production process.

B. *System Architecture Design*

As the water-saving irrigation monitoring systems for the soil temperature and humidity and other information, according to user needs and the actual environmental study, a plentiful

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monitoring points are needed and the monitoring area is dispersed. If using a simple point-to-point management approach, managers must face a huge number of monitoring points, which is not conducive to managers for managing and analyzing the collected data. Therefore, through wireless sensor networks, collecting monitoring points are connected together by wireless means, and users only need a data management center to manage a wireless network, which greatly reduces the number of user management. The overall structure of system is shown in Fig. 1, which is based on ZigBee tree topology and includes sensor nodes composed of ZigBee terminal nodes, gateway nodes served by the ZigBee coordinator, and the monitoring center composed of a PC and related management software. The task of sensor node is to collect soil environmental data, such as temperature and humidity, and transmit the data to the gateway node. Gateway node is responsible for receiving data information and communicating with the monitoring center by the serial port. The monitoring center provides a graphical operating environment and displays data for the staff to query.

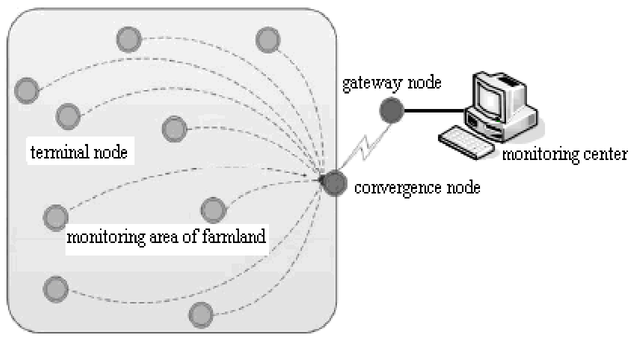

Figure 1 Systems architecture

III. SYSTEM HARDWARE DESIGN

A. The Hardware Design of the Terminal Node

In the background of soil water-saving irrigation monitoring applications, for the design of sensor node these factors such as low-cost, low power, stability, and reliability are specially considered. The hardware block diagram of terminal node is shown in Fig. 2.

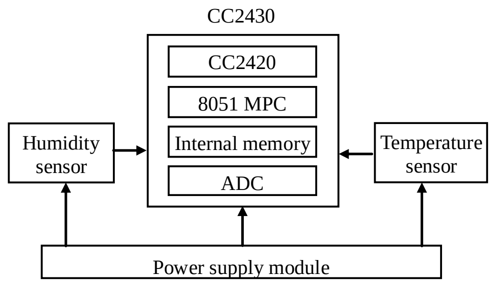

Figure 2 Terminal node hardware design

The CC2430 is the processor and wireless communication unit of system, which follows the usual structure of the chip CC2420, equipped with a high performance 2.4GHz DSSS (Direct Sequence Spread Spectrum) RF transceiver core, an enhanced industry-standard 8051 MCU and 128 KB programmable flash memory, 8KB SRAM, one general-purpose 16-bit timer, dual 8-bit timer, one MAC timer, an 8-input 8-bit to 14-bit ADC, two USART (Universal Synchronous/Asynchronous Receiver/Transmitter) that supports multiple communication protocol and 21 general I/O pins. This chip does not require patent licensing fees and can easily deploy and complete the task in many application environments. The CC2430 converts the collected data from the terminal node into digital signals using AD converter, then the data are transmitted to the gateway node by wireless multi-hop mode. The system frequency band is 2.4 GHz, which is currently the global preferred frequency band in sensor networks, and the transmission rate is 250KB/s.

Taking into account the specific task of the gateway node, that is to process and transmit the collected soil information, as well as the characteristic of its storage capacity and communications requirements for monitoring water-saving irrigation parameters, the gateway node can still use the CC2430, which is similar to the sensor nodes. The function of gateway node is to complete the correction and fusion of data, sending the data to the monitoring center, getting instructions and sending the instructions to the control equipment after processing. Wireless transceiver module includes CC2430 and related peripheral circuits. For the purpose of communication between gateway node and monitoring computer, the P3.0 port (serial data receiver) and P3.1 port (serial data transmitter) of microprocessor are used. In this design a MAX232 level converter chip was used to convert a TTL level output from the microprocessor into RS232 level of PC.

B. The Hardware Design of Sensor Measuring Circuit

In order to achieve automation, intelligence requirements, the data collection capabilities of water-saving irrigation environmental can be achieved using appropriate sensors. And in order to reduce the size of the circuit design and reduce system complexity, the smart sensor incorporating temperature and humidity collecting function is adopted. The energy consumption, measurement range, accuracy, cost, and size are the primary consideration in the choice of sensors. The soil temperature and humidity sensor TDR-3A is used that can measure the humidity and with the characteristics of waterproof and seal adaptable to the soil environment. The range of humidity measurement is 0~100%, the accuracy in the range of 0 to 50% is ±2% and the output current is 4~20 mA. The output of sensor can be directly connected to port P0 of CC2430.

IV. FUZZY PID CONTROL STRATEGY AND DESIGN

A. Fuzzy PID Control Strategy

PID (Proportional-Integral-Differential) control is one of the most widely used control strategy in the process control, in which integral action can reduce the steady-state error, and derivative action can improve the response speed. But on the other hand, the integral action easily leads to integral saturation, which makes the system overshoot increase and the differential action is particularly sensitive to high frequency interference, which even leads to system instability. PID control is essentially a linear control. PID control algorithm has the characteristics of simplicity, strong robustness and high reliability, widely used in industrial process control, especially for the certainty control system, in which precise mathematical model can be established. But the actual industrial production process is often nonlinear, time-varying and uncertainty, which makes it difficult to establish a precise mathematical model, and due to the complex parameter tuning method, the tuning effect is often bad, the performance is poor and the adaptability to the operating conditions is poor. Fuzzy controller doesn't need to master the precise mathematical model of controlled object, according to manual control rules to organize the control decision table, and then to determine the control amount by the control decision table. Because fuzzy control with certain intelligence is a nonlinear control in nature, if we use the fuzzy control based on some rules of the design of PID controller, which on the one hand makes the PID controller have the smart characteristic of fuzzy control, and on the other hand makes the PID controller have the determinate structure, so the designed controller has the advantages belonging to two types of controller.

In view of the characteristics of water-saving irrigation soil temperature control, that is, multi-variable, large inertia, nonlinear, coupling parameter, pure delay and a longer time spent in the control and regulation and producing significant overshoot, and taking into account heating device's large hysteresis and nonlinearity, a precise mathematical model cannot be established and using the classical control method is difficult to achieve satisfactory control precision. Since it is difficult to achieve high-precision uniform warm-up temperature control, and meanwhile the system performance is largely dependent on the accuracy of temperature control, fuzzy control strategy is a good choice. As an important branch of the field of intelligent control, fuzzy control strategy mimics the human thought to control, with simple design and robust advantages. Therefore, selecting a fuzzy control algorithm is to control the environmental factors of the system, and fuzzy control system was designed using software tools.

B. *The Implementation of Fuzzy PID Control*

The method of PID control is simple, however, parameter tuning is difficult when the parameters within the system are changed or disturbed by the outside environment, and so Fuzzy-PID compound control is used in this design. In control strategy the Fuzzy-PID algorithm has achieved good results after it is introduced to the temperature control system. In this design the fuzzy controller can meet the different requirements of the temperature error *e* and error change rate *ec* of the current system to the PID self-tuning and can realize fuzzy reasoning based on fuzzy control rules.

By identifying the characteristics of the system deviation to establish one-to-one correspondence between the deviation *e*, error change rate *ec* and the linguistic values of duty cycle change rate, then the fuzzy rules are established using the product strategy. The structure of fuzzy PID controller is shown in Fig. 3.

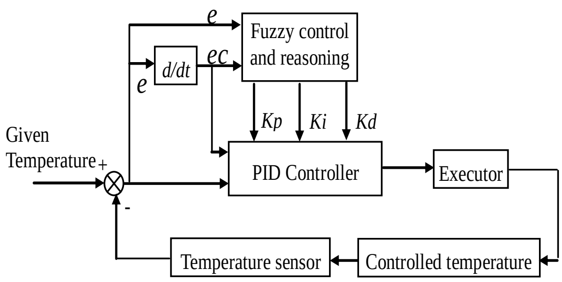

Figure 3 Fuzzy PID temperature controller structure

The PID controller starts to work when the absolute value of deviation is less than the feature setting value, and proportional coefficient K_p is set to a smaller value, integral coefficient K_i is set to a larger value, the differential coefficient K_d is set to a smaller value, which can reduce the overshoot, improve the steady-state accuracy and increase the disturbance rejection. For the established fuzzy control rules, in order to work out a fuzzy subset of control variables, fuzzy reasoning is needed, but a fuzzy variable cannot directly control the controlled object, and also needs to take a reasonable approach to convert the fuzzy variable into a precise variable, so as to improve the effects of the fuzzy reasoning results. In this design, the barycenter theory is used to process the fuzzy variable and to get a precise output control variable, which is made into fuzzy control query table, as shown in Table 1.

TABLE I. FUZZY CONTROL QUERY TABLE OF TEMPERATURE

e	***ec***								
	-4	-3	-2	-1	0	+1	+2	+3	+4
-3	-5	-4	-4	-3	-2	-1	-1	0	+1
-2	-5	-4	-3	-2	-1	-1	0	+1	+2
-1	-4	-3	-2	-1	0	0	+1	+2	+2
0	-3	-2	-1	0	0	+1	+2	+2	+3
+1	-2	-1	0	0	+1	+1	+2	+2	+3
+2	-1	0	0	+1	+1	+2	+2	+3	+4
+3	0	+1	+1	+2	+2	+3	+4	+4	+5

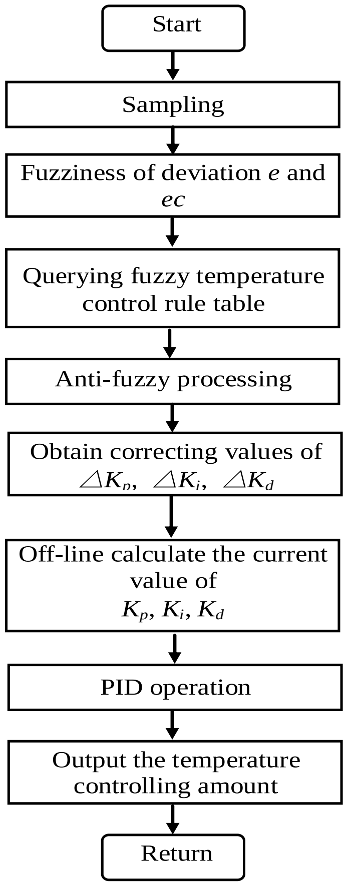

Figure 4 Fuzzy PID temperature control flow chart

Software part is an important part of the temperature control system, of which the key is the realization of fuzzy reasoning, that is, how to use the look-up table method to realize the fuzzy inference process using fuzzy rules. The specific implementation method is to store respectively the fuzzy control table of ΔK_p, ΔK_i and ΔK_d calculated off-line in the memory, then every 30ms periodic interrupt calls the subroutine of querying fuzzy control table, that is, according to the quantitative value of *e* and *ec* to query fuzzy control table and to obtain quantitative values of ΔK_p , ΔK_i and ΔK_d . The program flow chart is shown in Fig. 4.

V. SYSTEM SOFTWARE DESIGN

A. The Software Design of Terminal Node

ZigBee protocol is a wireless communication technology standards developed by the ZigBee Alliance. The device complying with ZigBee protocol has the functions of energy detection and link quality indication, and can automatically adjust the transmit power according to test results and can consume minimum equipment energy on the premise of ensuring the communication link quality. In this design, for the need of water-saving irrigation monitoring, wireless sensor network using a tree topology structure has the advantages of better function and larger coverage than the star structure, while easier to implement and maintain than the mesh network. In the software design of nodes, by calling the API functions provided ZigBee protocol stack to complete the initialization of device, the configuration of the network and the starting up network of network management layer, and then the wireless ad hoc network consisted of wireless sensor nodes distributed in a number of agricultural soils are achieved. To further reduce node power consumption, the system also has the function of the regular data collection and regular sleep and wake-up.

Sensor node module mainly includes data collection, integration, and delivery. System software architecture includes sending and incepting communication program and initialization programs. The software flow chart of the terminal nodes is shown in Fig. 5.

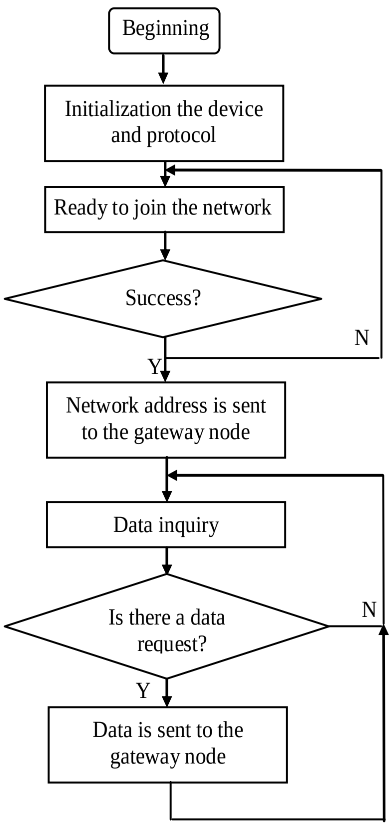

Figure 5 Software flow chart of the terminal nodes

The initialization program mainly performs initialization for the SPI (Serial Peripheral Interface) of RF (Radio Frequency) chip; the sending program sends the packaged packets to the RF generation module through the SPI interface of RF chip and outputs the packets; the incepting program completes the receiving and processing of the collected terminal data. The task of sensor node is to collect soil environmental data and transmit the data to the central control node, while receiving data from the central control node and taking corresponding operation according to these data.

B. The Software Design of the Monitoring Center

The function that environmental monitoring platform of water-saving irrigation can achieve involves the remote management of wireless sensor networks, including access to network status, access to node configuration information and changes of node configuration, etc. Monitoring platform can obtain network information through communication interface and display information on the graphical interface of windows platform. For wireless sensor network deployment, configuration, and optimization, monitoring has important application value. The commands of user thus are issued and ultimately sent to WSN through the communication interface. The returned data from the sensor network can also be transmitted from the communication interface to the end user and displayed. Monitoring platform needs to display dynamically network status data returned from sensor networks, such as node information of neighbor, and provides the interface for configuration of information display. The Block diagram of monitoring software is shown in Fig. 6.

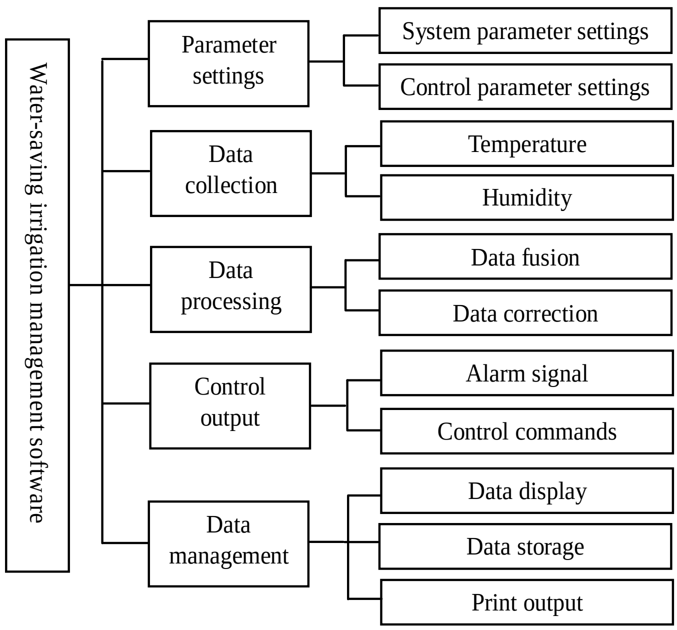

Figure 6 Block diagram of monitoring software

The main functions of monitoring center are in charge of communication with the gateway node located in the control room through the RS232 serial port, thus receiving the information from sensor node. The monitoring center software also achieves man-computer interaction, network management, receiving sensor information, data processing and analysis and database management, etc. The monitoring software is developed using Visual C++6.0. The communication control Mscomn of VisualC++6.0 can provide the full functionality of serial communication, and read data from serial port or write data to the serial port. The programming and debugging are simple, convenient, and fast, which can achieve a good user interface to meet the basic needs of wireless sensor networks.

A large number of sensor data, including the node address information, routing information, and environmental information of cycle perception, will be generated after monitoring system is started, and will be storied, managed, queried, inserted, and deleted, and these operations are related with the system database. So the purpose of developing environmental monitoring database is to maintain and manage the various data generated in the process of monitoring environmental information, which is convenient to manage the information of node status, sensor status, node-aware statistical information and related information, and to provide data sharing for other business and information systems.

The monitoring center management system is sending acquisition command, receiving collected data, while releasing data on the server to meet the client's browsing. Its main tasks include synchronous monitoring of all flow meters to achieve the online monitoring function of excessive alarm etc., collecting data and performing cyclic redundancy check (CRC) to ensure reliable data, storing automatically the monitoring data and time information in the database server, and so on.

VI. SYSTEM TEST RESULTS AND ANALYSIS

A. *Test Environment*

For the common soil environment in water-saving irrigation, using of wireless sensor network technology, a water-saving irrigation monitoring system is researched and designed. This system can achieve real-time monitoring for a variety of environmental factors in the soil affecting the growth of crops and can provide help for users with scientific irrigation, which provide a viable new method to further reduce irrigation costs, optimize the process of irrigation, increase water-saving irrigation efficiency and achieve water resources conservation.

The system was designed and completed based on multiple detection and controls, combined with the latest wireless ad hoc network technology. After the design is completed, the system is tested. According to design requirements, the temperature and humidity in the soil parameters were monitored actually, and taking into account the cost of research and test, according to need, in the wheat fields (about 100 square meters), where 3 temperature and humidity sensor terminal nodes (setting the number for the #1 ~ #3, burial depth of about 15 cm) and a convergence node are arranged manually, the soil environmental parameters were detected. The data acquired from three terminal nodes in real time are sent to the monitoring center via convergence node and gateway node.

B. *Testing Process and Results*

By the testing, within the 15m range temperature and humidity sensing nodes can pass through the obstructions and can achieve data collection, transmission. The network is good in the self-correcting ability and the data accuracy. Once the test parameters overrun, the computer will display address and gauge parameters and alarm, and the response time of computer is generally less than 3s. The monitoring data of three nodes at several time points are shown in Table 2.

TABLE II TABLES OF TEMPERATURE AND HUMIDITY MEASUREMENTS

Measurements (Three Nodes)		**Time of Temperature and Humidity Measurements**								
		8:00	***8:30***	***9:00***	***9:30***	***10:00***	***10:30***	***11:00***	***11:30***	***12:00***
Temperature (℃)	#1	15.1	15.2	15.2	15.4	15.6	15.7	15.8	15.9	16.1
	#2	15.2	15.2	15.3	15.4	15.5	15.7	15.8	15.9	16.1
	#3	15.2	15.3	15.2	15.4	15.6	15.8	16.0	16.0	16.2
Humidity (%)	#1	65	65	64	64	63	63	62	62	62
	#2	66	65	64	65	63	64	62	63	62
	#3	65	66	64	64	64	63	62	63	62

From Table 2, it may be seen that the measured data are more accurate, located in the vicinity of the best value. By actual measuring and calculating, it can be concluded that temperature measurement error is less than ±0.2℃, and relative humidity measurement error is within 2%. The temperature and humidity curves are shown respectively in Fig. 7 and Fig. 8.

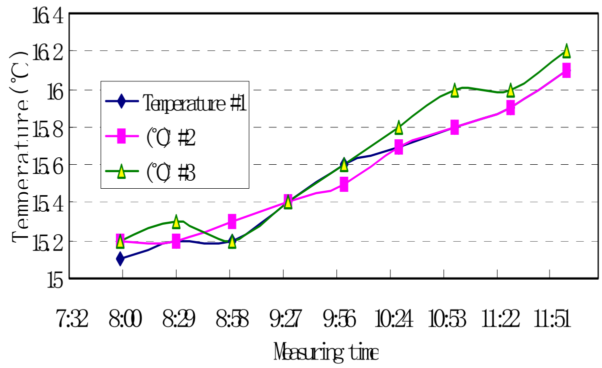

Figure 7 Curve of temperature measurements

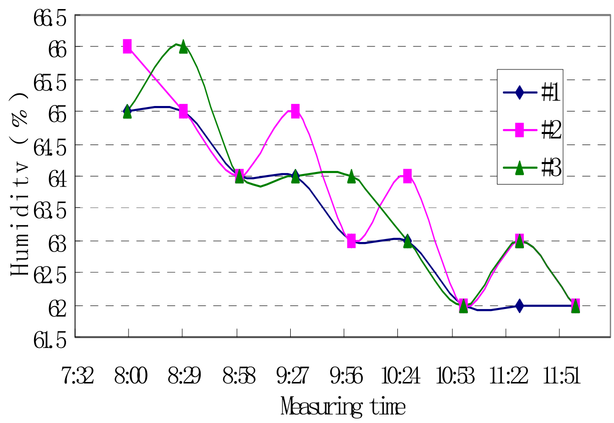

Figure 8 Curve of humidity measurements

The test results show that this system has performed well and the average packet transmission rate is 88.5%. The soil temperature and humidity measurement sensor with low-cost, low power consumption can be used for large-scale and full-coverage monitoring. Communication between nodes in the system follows the ZigBee protocol, which ensures the stability of the system running and low power consumption. conclusions

In this paper, aiming at the disadvantage existing in the current monitoring system of water-saving irrigation environment, a real-time soil temperature and humidity monitoring and controlling system based on ZigBee CC2430 and fuzzy PID strategy was designed. The system can achieve rapidly ad hoc networks of sensor nodes, and can achieve real time collection, transmission, and display of soil environmental factors. The management system of soil environmental parameters based on embedded database can effectively manage various sensor nodes and a large number of environmental data. The system has the advantages of low-cost, low power, no wiring, flexible networking, and friendly interface and so on. The results have shown that this system can promptly detect changes in soil temperature and humidity and can control the decisions. In the process of implementation of water-saving irrigation, applying the wireless sensor network technology to monitor temperature and humidity information of irrigation environmental will provide a new access to information and to change the traditional management methods, which have some practical significance to improve the quality of the water-saving irrigation, reduce production costs and reduce the work intensity of workers and so on. The entire system achieves the functionalities of ZigBee wireless network and environmental monitoring of water-saving irrigation. Compared with the traditional environmental monitoring system, this monitoring system has the features of free wiring, easy maintenance, scalability, and flexibility. Since ZigBee wireless network can be independent of the specific application environment, this system can be easily extended to other application areas after making the appropriate changes.

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