Real-time remote monitoring system for crop water requirement information

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Abstract: Rapidly acquiring and real-time transmitting crop water requirement information constitute the basis for achieving intelligent diagnosis and precision irrigation. In order to collect and transmit crop water requirement information at real time, a new microcontroller-based real-time remote monitoring system was designed, including system hardware design, software and anti-jamming design. The system achieved the functions including clock reading, information configuration, LCD display, keyboard control, data sending and receiving, multi-channel information acquisition, conversion and storage. Laboratory and field tests showed that the system can achieve data acquisition and real-time display of the crop water requirement information. Unlike the current weather station, the system collects crop water information, meteorological factors and soil parameters at the same time. It has a high level of stability and acquisition accuracy, and can meet the requirements for real-time remote monitoring of the crop water requirement information for irrigation decision-making.

Keywords: crop water requirement, information collection, microcontroller, real time monitoring, irrigation decision making
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1 Introduction

With the scarcity of water resources exacerbated, the demands of agricultural water restrictions caused the transformation of agricultural water usage, which converts from an extensive irrigation mode to a precision mode with advanced technology. In that case farmland irrigation requirements may be satisfied with the limited water resources[1]. Information technology is one of the fundamental methods of achieving intensive precision irrigation with agricultural water and regional intelligent precision water management. Real-time monitoring of crop water requirement information is the prerequisite for the accurate and rapid evaluation of the water requirement situation and the important foundation for decision making and the management of precision irrigation[2-6].

The development of modern electronic technology and mobile wireless communication technology has provided effective methods for the collection of crop water requirement information[7-9]. EL-Magd et al.[10]

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designed a remote sensing and geographical information systems (GIS) for estimation of irrigation crop water demand based on satellite images and Penman equation. Wang et al.[11] designed a remote monitoring system for farmland environmental information based on the general packet radio service (GPRS); This system uses a microcontroller as the central processor. Casa et al.[12] carried out an estimation of the crop water requirements for the Pontina Plain, Central Italy through the use of remote sensing land classification and application of a simple water balance scheme in a geographical information system (GIS) environment. Based on embedded technology, Li et al.[13] designed and studied the farmland environmental information collection system using the ARM7 processor and GPRS. Fisher et al.[14] studied a microcontroller-based system for monitoring the crop canopy, air temperature, soil temperature, and humidity to determine the crop water requirement status. Rossi et al.[15] studied the moderate-resolution imaging spectroradiometer (MODIS) satellite remote sensing time-sequence imaging system for monitoring the continuous change of crop parameters, combining the system with the Penman equation to estimate the crop water requirement status. Gao et al.[16] studied a crop water monitoring system based on wireless sensor networks and developed the crop water information management and diagnostic system on the host machine.

Most previously published studies have developed monitoring systems related to irrigation like weather station and soil moisture sensors. The data cannot be used for evaluation on crop water requirement directly[17,18]. In the present study, a monitoring system was developed specially for crop water requirement evaluation. The FAO Penman-Monteith water requirement calculation equation was used to determine the indicators that must be monitored, such as the air temperature, air humidity, solar radiation, sunshine duration, wind speed, and soil moisture. Through sensor selection, the required signal type and number of channels were determined. Next, using the time-sharing multi-channel data acquisition structure, a microcontroller- zbased crop water requirement information monitoring system was developed especially for the diagnosis of crop water shortages.

2 Materials and methods

2.1 Determination of monitoring indicators for crop water requirement

According to the FAO Penman-Monteith equation, the required input data include the air temperature, air humidity, solar radiation, sunshine duration, wind speed, and barometric pressure. This system employs these indicators as the basic data for crop water requirement diagnosis and decision making. The acquisition indicators and their range of technical parameters, as determined in the present study, are listed in Table 1.

Table 1 Monitoring indicators for crop water requirement and their technical parameters

Measured elements	Measuring range	Resolution	Accuracy	Channel number
Air temperature	-50～+50℃	0.1℃	±0.2℃	1
Air humidity	0～100%	1%	±4%	1
Sunshine hours	0 - 24 h	0.1 h	±0.1 h	1
Solar radiation	0～2000 W/m^2	1 W/m^2	⩽5%	1
Soil moisture	1～100%	0.1%	±2%	1
Wind speed	0～60 m/s	0.1 m/s	±(0.3 + 0.03 V) m/s	1

2.2 Selection of sensors

In the present study, based on the acquisition indicators and parameters determined by the system, the Model FDS-100 soil moisture/humidity sensor produced by Lianchuang Company, Beijing, China) was selected. The sensor range is 0-100%. The accuracy is up to ±2% between 0-50% with the operating temperature range of -40 ℃ to 85 ℃. The operating voltage is 24 V, and operating current ranges from 25 to 45 mA, with a typical value of 28 mA. The output signal consists of the analog output voltages of 0-2 V DC. The response time is less than 1 s.

The Voltage-CG-01 outdoor air temperature and humidity transmitter (Handan Qingsheng Electronic Science Technology Co.) was selected as the air temperature and humidity sensor. The sensor’s operating voltage is 7-12 V DC. The analog voltage signal output range is 0-2 V. The corresponding temperature is from -30 ℃ to 70 ℃, with an accuracy of ±0.2 ℃. The corresponding humidity is 0-100%, with an accuracy of ±3%.

The selected wind speed sensor is QF-FS wind sensor (Handan Qingsheng Electronic Science Technology Company) with range from 0 to 32.4 m/s and supply voltage of 12 V DC. The analog voltage signal output ranges from 0.4 to 2 V with accuracy is ±1 m/s, and the lowest detectable signal is 0.2 m/s.

The HTSD1 digital sunshine recorder (Beijing Huatron) was selected as the sunshine duration sensor. The spectral range is 0.4 to 1.1 μm. The sensor irradiance range is 0-2 000 W/m^2. The supply voltage is between 6 and 15 V DC. The sampling interval is 60 s. The digital output signal (TTL) output is +5 V when greater than or equal to 120 W/m^2, and the output is 0 V when less than 120 W/m^2. The accuracy is ±0.1 h. The resolution is 0.1 h. The response time is less than 1 s.

The FNP-net solar radiometer produced by Beijing Huatron was selected as the net solar radiation sensor. The sensor signal range is -300 to +1 000 W/m^2. The supply voltage is 12 V DC. The analog voltage signal output ranges from -20 to +20 mV. The sensitivity is 7-14 μV/W m^2. The response time is less than 35 s (99%). The sensing surface precision is ±15%.

2.3 Method for calculating crop water requirement

Crop water requirements may be determined by calculating the crop evapotranspiration. Crop evapotranspiration may be calculated using Equation (1):

$$ET_c = K_c \cdot ET_o \tag{1}$$

where, ET_c is the evapotranspiration under the condition of adequate water supply, mm; K_c is the crop coefficient, a measure of the crop transpiration characteristics, which are related to the types of crops, the growth stages, and other factors; ET_0 is the reference crop evapotranspiration, mm.

ET_0 is crucial for the indirect method of calculating crop water requirements. It is the main parameter for crop water requirement estimation, real-time irrigation forecasting, and agricultural water management (Shang et al.[19]). Jensen et al.[20] used 20 types of calculation or measurement methods for evapotranspiration and compared them with the actual measurement result from Lysimeter. The researchers concluded that in both arid regions and humid areas, the FAO Penman-Monteith equation was the best calculation method. The effects of the various meteorological factors on ET_0 were comprehensively considered in the FAO Penman-Monteith equation, which has a reliable physical basis. After decades of theoretical research and practical application, the FAO Penman-Monteith equation has become a recognized and standard method of computing crop water requirements using meteorological parameters. The FAO Penman-Monteith equation is:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_\alpha)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2}$$

where, ET_o is the reference crop water requirement, mm; Δ is the slope of the saturated vapor pressure and temperature curves, MJ/m^2 d; R_n is the net solar radiation, MJ/m^2 d; G is the soil heat flux, MJ/m^2/day; γ is the hygrometer constant, kPa/^{o}C; T is the average temperature during the period of calculation, ^{o}C; u_2 is the average wind speed at 2 m above the ground, m/s; e_s, e_α are the saturated vapor pressure and the actual vapor pressure, kPa.

3 System design

3.1 System input channel program determination

The common structure of the multi-channel data acquisition system includes a timesharing multi-channel acquisition structure, a pseudo-synchronous multi-channel acquisition structure, and a simultaneous multi-channel acquisition structure[21-23]. The first multi-channel acquisition system structure can achieve multi-channel asynchronous sampling. The second and third multi-channel data acquisition system architectures can achieve multi-channel synchronous sampling. For the multi-channel analog signal acquisition system, if high-speed acquisition is not required, then the common A/D converter may be used. Multi-channel analog switches can be used for channel switching between multi-channel analog signals and A/D converter channels so that, within a specific amount of time, only one of the analog signals can be input to the A/D converter, thereby achieving time-sharing multi-channel conversion[24]. In the present study, the required parameters (such as the air temperature, humidity, radiation, wind speed, sunshine duration, and soil moisture) are relatively slowly changing variables. Therefore, in addition to reducing costs, this system selected the first scenario, which is a time-sharing multi-channel asynchronous data acquisition system structure (shown in Figure 1). The multi-channel analog switches were used to increase the number of channels for the analog signal. After being amplified and filtered, the analog signals were input to an analog multiplex (MUX) switch under the control of the CPU; the signal selected one random channel and went to the buffer amplifier or to the sample holder (S/H) in the next level. Next, the signal fed into the ADC (analog/digital converter input multiplexer) for conversion between analog and digital signals. The conversion result was a binary digital value, which was ultimately fed into the CPU for processing.

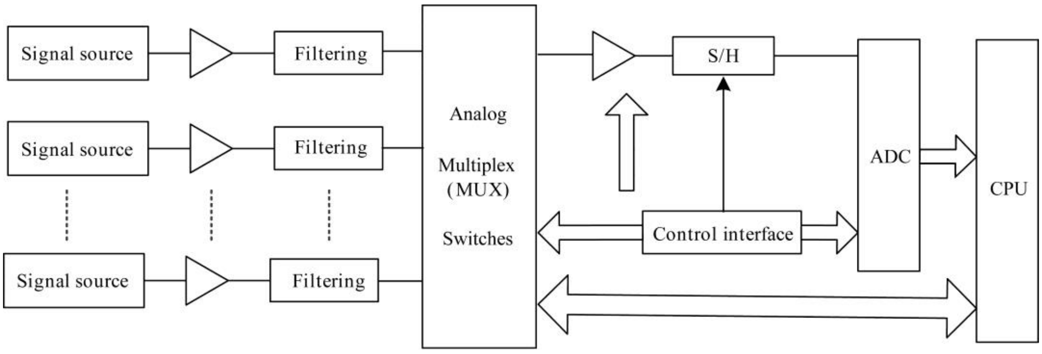


Figure 1 Timesharing multi-channel acquisition system structure

3.2 Overall design of the monitoring system

The overall design of the remote real-time acquisition system for crop water requirements is shown in Figure 2. Basically, the system includes the combination of a crop water requirement sensor, microcontroller, multiplexer, sampler/holder, A/D converter, data memory, keyboard, real-time clock, LCD, power, and GPRS module. The MSP430F149 microcontroller is used in the system integrated multiplexer, sample/hold, A/D converter. The main function of the system is the acquisition, sample/hold, A/D conversion, storage, display, and transmission of the signal output from the sensors or the transmitter.

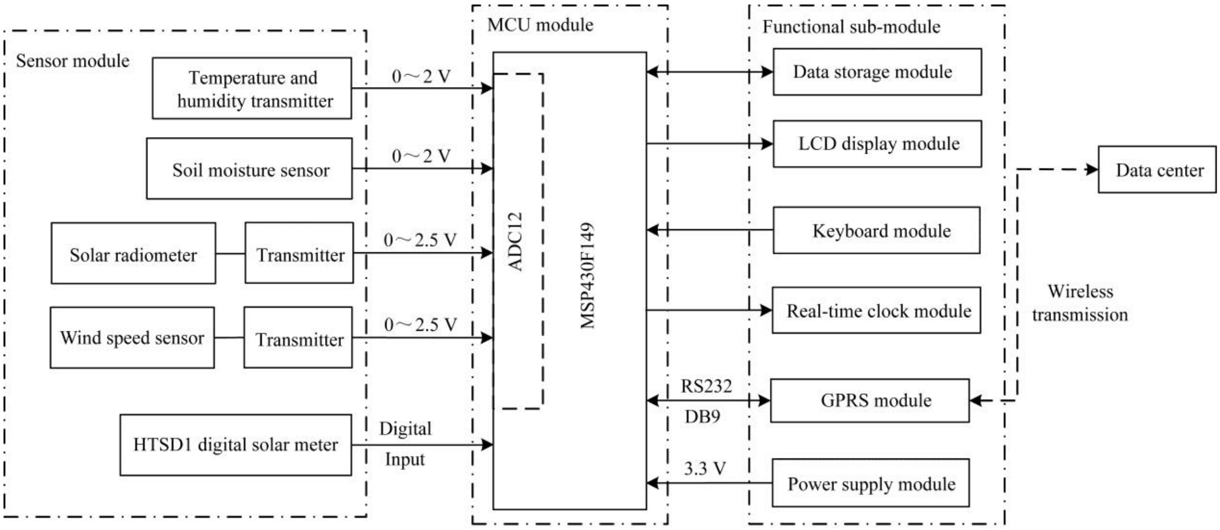
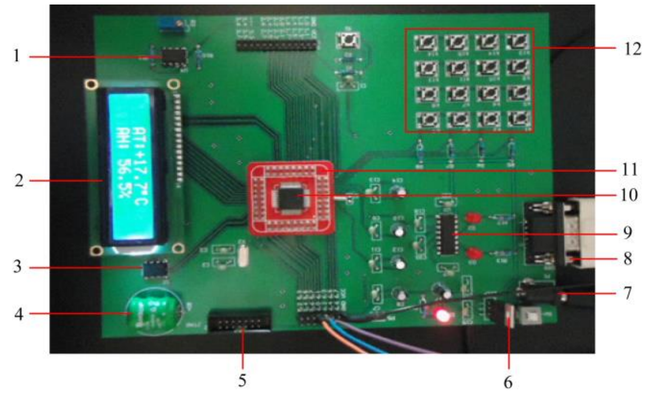


Figure 2 Overall design of the system

3.3 System hardware design

The crop water requirement information monitoring system’s microcontroller and functional modules are displayed in Figure 3.

The crop water requirement information remote real-time acquisition system operates in the field for long periods; therefore, its energy consumption should be low. In the present study, the MSP430 single chip microcontroller (SCM) manufactured by Texas Instruments (TI) was selected. The SCM is a 16-bit ultra-low-power microprocessor, which has 64K Flash ROM and 2K RAM memory and many on-chip peripherals. Additionally, it contains an on-chip built-in analog-to-digital converter (ADC12).



1. E^{2}PROM memory 2. LCD display 3. DS1302 real-time clock chip 4. 3.6 V battery 5. JTAG interface 6. 3.3 V three-terminal regulator 7. Standard power interface 8. RS232 interface 9. MAX3232 10. MSP430F149 11. Microcontroller conversion block 12. Keyboard module

Figure 3 Photograph of the system microcontroller and functional modules

The crop water requirement information collection system provides basic data for a decision-making support system for crop irrigation. The signal acquisition time must be recorded for crop irrigation decision analysis. For recording the time, the system uses the DS1302 real-time clock chip, which is produced by the American DALLAS Company.

The crop real-time remote water requirement information acquisition system is used for the long-term acquisition of crop water requirement information in agricultural fields. It operates over long periods in an unguarded state. The self-contained data memory (RAM) on the MSP430F149 does not satisfy the requirements of the system. The serial, electrically erasable, and programmable read-only memory (E2PROM) AT24C512 manufactured by ATMEL, which was utilized in the present study, has an I2C bus interface with a capacity of 512K bit, which fully meets the system data storage requirements.

In the SCM data acquisition system, the commonly used monitors were light-emitting diode (LED) and liquid crystal display (LCD) types. Based on the system power consumption requirements, an LCD display (model SMC1602A) was selected.

The system configuration information parameters, such as the collection time interval, must be input sometimes. Therefore, a keyboard for data input and command transfer was required. A matrix keyboard was used in the system to configure the information parameters. The matrix keyboard circuit mainly used the P1 port of the MSP430F149 microcontroller for extended design. The circuit consists of row lines and column lines and captures the keyboard input by scanning. The P1 port of the MSP430F149 microcontroller has an interrupt function. For software design, the general I/O port can be used for keyboard input; alternatively, the P1 port interrupt function may also be used to achieve the key input.

The acquisition terminal in the crop water requirement information acquisition system requires a voltage supply of +5 V and +3.3 V. The sensors that collect all of the water requirement information require a voltage supply of +3.3 V. Because the monitoring terminal of the crop water requirement information collection system is used in agricultural fields, where AC power supplies may not be available, adequate power equipment and power supplies are necessary for the data acquisition system. For locations with an AC power supply, the system's power supply may be provided by the power conversion circuit. For locations without an AC power supply, solar batteries may be used to supply power to the system. In the unmanned, remote work environment, 5 V/12 V dual output solar batteries were used in the system design: the 5 V is used for the data acquisition input voltage and is converted to 3.3 V, a typical supply voltage value for the MSP430F149 microcontroller, by an LM1117 3.3 V chip. The LM1117 chip has many fixed voltage output series. LM1117-3.3 has a fixed output voltage of 3.3 V, with an input voltage V_{in} in the range of 4.75-15 V. The 12 V solar battery supplies voltage to each sensor.

The serial communication interface is the main interface between the microcontrollers and between the SCM system and the other systems. MSP430F149 integrates a serial synchronous/asynchronous communication module (USART). This system employs asynchronous communication and uses an RS232 Universal Serial Interface to send the data acquired from the crop water requirement information collecting system to the GPRS module for wireless transmission. To connect with the TTL devices, there must be level and logical relation changes between the

RS-232 and TTL circuits. In the present study, the MAX3232 chip was selected to complete the bi-directional level switching between TTL and RS-232. A SIM300 module manufactured by Shanghai SIMCOM Company was chosen as the GPRS module.

3.4 System software design

The crop water requirement information real-time remote acquisition system terminal must not only process commands from the communication interface and keyboard, thereby achieving human-computer dialogue, but also requires real-time processing capabilities to send various measurement and communication tasks based on the interrupt request. According to the design requirements of the hardware, the programs that must be obtained via software programming include the system initialization program, the A/D conversion routine, the real-time clock subroutine, the LCD display subroutine, the keyboard processing routine, the data storage routine, the serial communication routines, the interrupt subroutine, and the written SIM300 instruction. The IAR Embedded Workbench provided by IAR was used for the system software development. The functional modules of the system software are displayed in Figure 4.

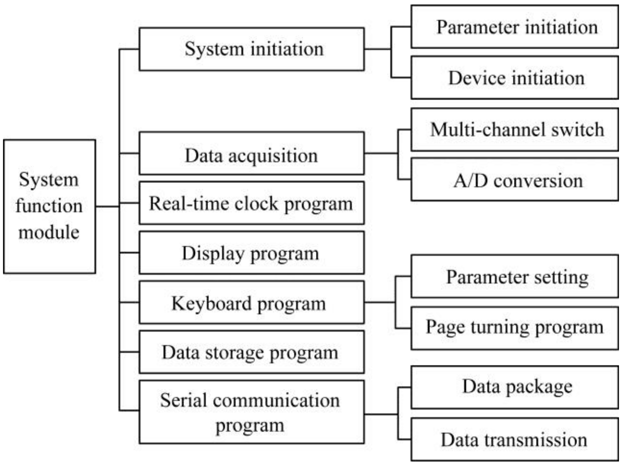


Figure 4 System software functional module

The flow chart of the main system program is displayed in Figure 5.

The SCM sends its acquired data to the data center through its associated SIM300 GPRS module. The data center is an ordinary PC that is connected to another SIM300 GPRS module, which can receive, display, and save the data that are sent from the lower computer GPRS module. A MFC (Microsoft Foundation Classes) programming technique was used for the data center interface, which can display the received data and time and save the received data and acquisition time[25].

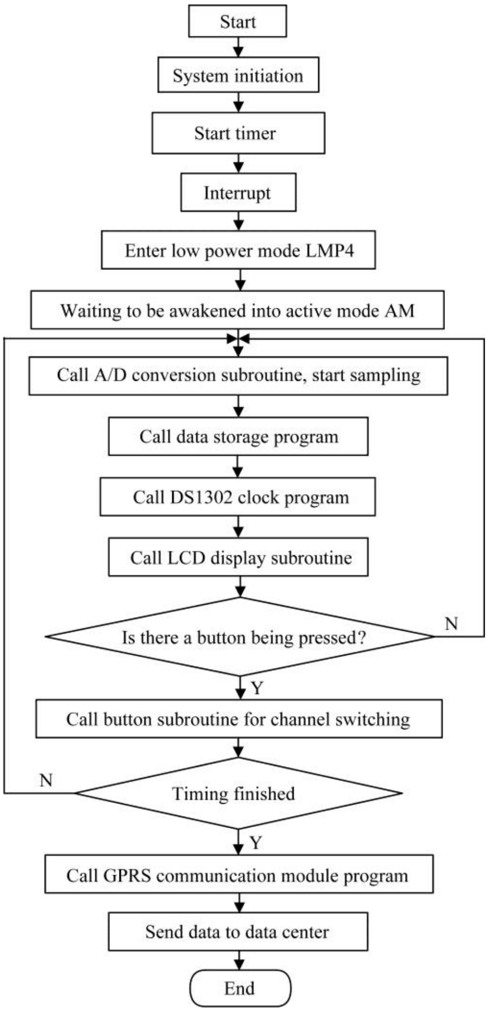


Figure 5 Flow chart of the main system program

3.5 Anti-jamming design of the system

The anti-jamming design of the crop water requirement information monitoring system includes a hardware and software design. In the hardware anti-jamming design, the system uses a three-terminal regulator power supply circuit to improve the stability of the power supply and inhibit the fluctuations and interference noise of the DC power supply voltage. The input between the power line and the ground line was specifically chosen to limit the power ripple of the chip input, which provided good interference suppression. For the printed circuit board (PCB), an attempt was made to place the related devices closer to obtain a better anti-noise effect. The digital and analog grounds of all the devices were grounded. The main integrated circuits (ICs) on the circuit board were connected in parallel to a

0.01-0.1 μF high-frequency capacitor to reduce the impact of the IC on the power supply.

The anti-jamming technology of the software used in the present system involves arithmetic average filtering and filters smoothly for the data after A/D conversion. The arithmetic average of 32 sampling data points was taken. The arithmetic mean was used to express the final result. The arithmetic mean filtering was performed according to the following formula:

$$y=\frac{1}{N}\sum_{i=1}^{N}x_i \tag{3}$$

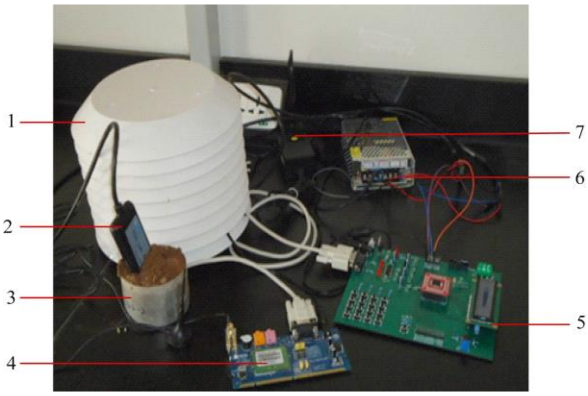
where, y is the arithmetic mean obtained from calculation; N is the number of sampling data; x_i (i=1, 2, ……, N) is the signal at each sampling.

4 System test

4.1 Laboratory test

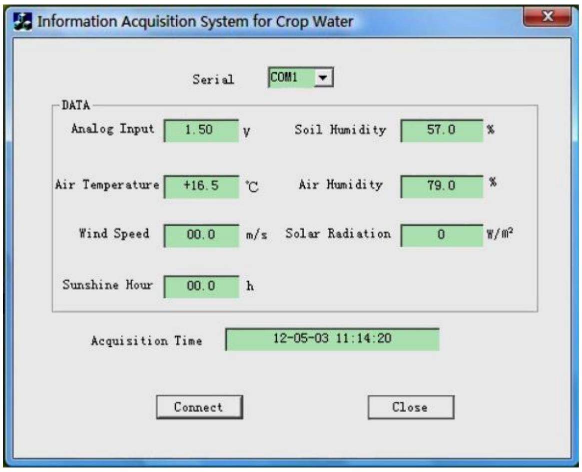
The system tested the air temperature, humidity, and soil moisture information collection, display, and signal sending and receiving. In the laboratory, the air temperature and humidity transmitter and the soil humidity sensors were powered by a 12 V voltage-switching power supply. The 5 V voltage required by the data acquisition terminals and SIM300 GPRS module was conveniently obtained from the power adapter on the laboratory AC. The air temperature and humidity transmitter output the measured laboratory air temperature and humidity. The soil moisture sensor collected the soil humidity data from the outdoor soil samples. The soil was placed in a cylindrical box. The amount of soil was sufficient to cover the entire soil moisture sensor probe. As verified by the experiments, the system can perform multiple functions, including acquisition, display, saving, and sending. The experiment configuration of the lower machine and its sensors is displayed in Figure 6.

The data acquisition terminal sent the data obtained from multiple channels to the laboratory data center, i.e., the host computer, using the short message service (SMS) function of the SIM300 GPRS module. The host computer received and saved the data through the connected GPRS module. The interface for receiving and displaying the collected data on the host computer is shown in Figure 7.



1. Air temperature and humidity transmitter 2. Soil moisture sensor 3. Measured soil samples 4. SIM300 GPRS module 5. Data acquisition board 6. Power supply switch 7. Power adapter

Figure 6 System for data-acquisition experiments


Information Acquisition System for Crop Water

Serial COM1

DATA

Analog Input 1.50 v

Soil Humidity 57.0 %

Air Temperature +16.5 ℃

Air Humidity 79.0 %

Wind Speed 00.0 m/s

Solar Radiation 0 W/m²

Sunshine Hour 00.0 h

Acquisition Time 12-05-03 11:14:20

Figure 7 Host computer data-acquisition interface

The data-receiving software in the data center received and saved data in the specified folder with the .TXT file format. The files were named according to the date. A sample of the saved experimental data is displayed in Figure 8.

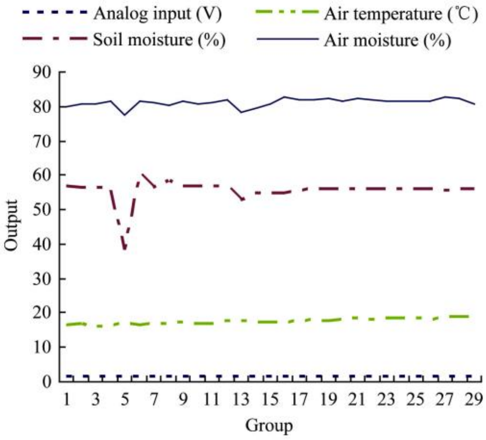


Figure 8 Real-time collected data

4.2 Error analysis

The system performed smoothing filtering of the data after the A/D conversion. An average of 32 sampling times was taken. The A0 channel collected the analog voltage output value of the potentiometer. By adjusting the potentiometer, eight groups of different voltage values within the range of 0-2.5 V were obtained. Each set of output voltage values was collected and displayed on the LCD. The displayed voltage was compared with the value measured by the VICTOR VC890D digital multimeter. Some of the voltage measurement data from the A0 channel are listed in Table 2.

Table 2 Voltage measurement via the A0 channel

Group	1	2	3	4	5	6	7	8
Display value/V	0.38	0.79	1.01	1.34	1.57	1.88	2.21	2.42
Standard value/V	0.39	0.79	1.01	1.35	1.57	1.88	2.20	2.41

From the data in Table 2, it was determined that the displayed value and the standard value are essentially coincident. As determined through the system acquisition, the A/D converter, and the processing, the displayed voltage value was either similar than or identical to that acquired from the digital multimeter measurement. Therefore, the system had high stability. The system's acquisition error (δ) computed from the first set of data was 2.56%. The computing formula is:

$$\delta = \frac{|V_{displayed} - V_{standard}|}{V_{standard}} \times 100\% \qquad (4)$$

The A1, A2, and A3 channels of the system collected air temperature, humidity and soil moisture data. Table 3 lists the air temperature and humidity values that were displayed on the LCD monitor. These values were compared with the air humidity and soil humidity values that were computed from the calibration formula, using the humidity transmitter and the soil humidity sensor output voltage. The LCD display value in the table was close to the calculated value that was based on the measurements. This finding indicates that the system data acquisition accuracy is high.

Table 3 Test results of the air temperature, humidity, and soil moisture

Measured parameter	Air temperature AT/℃	Air humidity AH/%	Soil moisture SH/%
LCD display value	+24.3	42.9	57.5
Measured value	+24.1	42.8	57.7
Corresponding voltage	1.425 V	1.084 V	1.154 V

4.3 Field test

The system A1 channel collected the analog voltage output value of soil moisture measured by the soil moisture sensor; the system A2 and A3 channel collected the analog voltage output value of air temperature and air humidity measured by the air humidity transmitter respectively. The test was done in the experimental plots in the Institute of Water Saving Agriculture in Arid Regions of China at 13:00 to 15:20 in 19th November, 2014 and 15:40 to 18:00 in 20th November, 2014. Three channels collected and transmitted data to the reception once every 20 min and 16 sets of data were collected and displayed on the LCD. The data displayed by LCD were compared with weather station value, which was placed 2 m far away, showed in Figure 9.

Figure 9 Field test

4.3.1 Results of soil moisture collection

The soil moisture data from the A1 channel are listed in Table 4.

Table 4 Soil moisture via the A1 channel

Group	Field test value/%	Weather station value/%	Group	Field test value/%	Weather station value/%
1	27.9	20.4	9	27.0	20.3
2	27.9	19.9	10	27.0	20.4
3	28.3	20.1	11	27.0	20.4
4	27.9	20.3	12	27.0	20.3
5	28.3	20.0	13	27.4	20.2
6	28.3	20.1	14	27.0	20.0
7	27.9	20.4	15	27.0	20.2
8	27.9	20.0	16	27.0	20.2

From the data in Table 4, it can be seen a large difference between field test value and weather station value. The large difference was mainly caused by three reasons. Firstly, soil moisture sensors used by two systems are from different manufacturer. Secondly, the soil moisture sensor of weather station was buried deeply in the ground by more than 20 cm, while the soil moisture tested by this experiment measured acquisition system was near surface (about 8 cm under ground).

4.3.2 Results of air temperature collection and comparison

Some of the air temperature data from the A1 channel are listed in Table 5.

Table 5 Air temperature via the A2 channel

Group	Field test value/°C	Weather station value/°C	Group	Field test value/°C	Weather station value/°C
1	14.5	14.8	9	21.5	16.5
2	15.0	15.2	10	20.6	16.1
3	15.4	15.4	11	19.7	16.0
4	15.6	15.4	12	18.6	15.7
5	15.3	15.6	13	17.7	15.3
6	15.3	15.8	14	15.5	14.6
7	15.6	16.2	15	13.6	13.5
8	15.0	15.8	16	11.6	12.6

The data in Table 5 show that the field test value and the weather station value are essentially coincident. The system’s acquisition error (δ) computed from the second set of data was 1.31%. Some of the data are quite different because of the sensitivity of the sensor is affected after sun exposure.

4.3.3 Results of air humidity collection and comparison

Some of the air humidity data from the A1 channel are listed in Table 6.

Table 6 Air humidity via the A3 channel

Group	Field test value/%	Weather station value/%	Group	Field test value/%	Weather station value/%
1	30.9	42.5	9	27.3	24.2
2	28.9	40.7	10	26.8	23.3
3	27.3	37.8	11	29.5	24.6
4	27.6	35.7	12	33.3	25.6
5	29.3	39.6	13	34.3	25.9
6	28.5	36.9	14	39.6	27.4
7	28.1	37.4	15	41.8	30.7
8	28.2	37.1	16	50.4	37.9

The data in Table 6 showed that the field test value and the weather station value are coincident. The system’s acquisition error (δ) computed from the ninth set of data was 12.8%.

5 Conclusions

Based on the Penman-Monteith Equation and the major environmental factors that affect the crop water requirements, an information acquisition system was designed and tested to monitor the air temperature, air humidity, sunshine duration, wind speed, radiation, and soil moisture. The system can test air temperature range from -50℃ to 50℃ with an accuracy of ±0.2℃, air humidity range 0-100% with an accuracy of ±4%. Based on the technical requirements of the crop water requirement monitoring and diagnosis, the time-sharing multi-channel acquisition structure and anti-jamming was designed. The arithmetic-average filtering method was used for smooth filtering of the data after A/D conversion. The developed crop water requirement information monitoring system performed clock reading, information configuration, LCD display, keyboard control, data sending and receiving, multi-channel analog information acquisition, data conversion and storage, and other functions. Laboratory and field test showed that air temperature and humidity measurement errors were 1.31% and 12.8%, which showed that the system had a good stability and acquisition accuracy and could meet the requirement for real-time remote monitoring of crop water requirement information. Soil moisture measurement error is due to the depth of the node and the poor performance of soil moisture sensor. The system can rapidly acquiring and real-time transmitting crop water requirement information, it can provide a basis for intelligent detection and precision irrigation.

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[References]

[1] Phene C J, Itier B, Reginato R J. Sensing irrigation needs. ASAE Publication, 1990; 90(4): 429–443.

[2] Han W T, Yao X M, Lao D Q, Wu P T. A dynamic-simulation system for sprinkler water 3d-distribution using multiple tools integration. Journal of Convergence Information Technology, 2013; 8(2): 170–176.

[3] Han W T, Wu P T, Yang Q, Feng H. Advances and comparisons of uniformity evaluation index of sprinkle irrigation. Transactions of the CSAE, 2005; 21(9): 172–177. (in Chinese with English abstract)

[4] Huang Y X, Han W T, Zhou L, Liu W S, Liu J D. Farmer cognition on water-saving irrigation technology and its influencing factors analysis. Transactions of the CSAE, 2012; 28(18): 113–120. (in Chinese with English abstract)

[5] Han W T. Calculation of sprinkler irrigation uniformity by double interpolation using cubic splines and linear lines. Transactions of the CSAM, 2008; 39(10): 134–139. (in Chinese with English abstract)

[6] Han W T, Wu P T, Feng H, Yang Q. Theoretical study on variable-rate sprinklers for high uniformity precision irrigation. Transactions of the CSAE, 2005; 21(10): 13–16. (in Chinese with English abstract)

[7] Sathish K, Thilagavathi G. Online farming based on embedded systems and wireless sensor networks. ICCPEIC 2013; 71–74.

[8] Chávez J L, Pierce F J, Elliott T V. Precision irrigation with wireless monitoring and control system technology. ASABE, 2010; 1: 258–269.

[9] Miskam M A, Rahim I A, Sidek O. Deployment of wireless water-quality monitoring system at Titi Serong paddy crop field, Malaysia. Proceedings-2013 IEEE 3rd International Conference on System Engineering and Technology, ICSET 2013; 57–60.

[10] EL-Magd I A, Tanton T. Remote sensing and GIS for estimation of irrigation crop water demand. International Journal of Remote Sensing, 2005; 26(11): 2359–2370.

[11] Wang Y L. Research of Field Information Remote Monitoring System Based on GPRS. Master dissertation, Jiangsu University, 2008. (in Chinese with English abstract)

[12] Casa R, Rossi M, Sappa G, Trotta A. Assessing crop water demand by remote sensing and GIS for the Pontina Plain, Central Italy. Water Resour. Manage., 2009; 23(9): 1685–1712. doi:10.1007/s11269-008-9347-4

[13] Li X X. Research of Field Environment Information Acquisition System Based on Embedded Technology. Master dissertation, Harbin Engineering University, 2009. (in Chinese with English abstract)

[14] Fisher D K, Kebede H. A low-cost microcontroller-based system to monitor crop temperature and water status. Computers and Electronics in Agriculture, 2010; 74(1): 168–73.

[15] Rossi S, Rampini A, Bocchi S, Boschetti M. Operational monitoring of daily crop water requirements at the regional scale with time series of satellite data. Journal of Irrigation and Drainage Engineering, 2010; 136: 225–231.

[16] Gao F, Yu L, Wang Y, Lu S Q, Zhang W A, Yu L J. Development of host computer software for crop water status monitoring system based on wireless sensor networks. Transactions of the CSAE, 2010; 26(5): 175–181.

[17] Liu B J, Shao D G, Shen X P. Advances in researches on the spatial-temporal features of crop water requirment. Transactions of the CSAE, 2007; 23(5): 258–264. (in Chinese with English abstract)

[18] Zhang J Y, Duan A W, Sun J S, Meng Z J, Liu Z G. Advances in automated monitoring and diagnosis of crop water status. Transactions of the CSAE, 2006; 22(1): 174–178. (in Chinese with English abstract)

[19] Shang H J, Ma X Y, Gao J E, Wang Z N, Zhao X N. Research on computing model components for crop water requirements and its application. Water Saving Irrigation, 2011; 8: 66–72. (in Chinese with English abstract)

[20] Jensen M E, Burman R D, Allen R G. Evapotranspiration and irrigation water requirements. ASCE Manual 70, 1990.

[21] Strobl R, Robillard P, Shannon R, Day R, McDonnell A. A water quality monitoring network design methodology for the selection of critical sampling points: Part I. Environmental Monitoring and Assessment, 2006; 112: 137–158.

[22] Greenwood D J, Zhang K, Hilton H W, Thompson A J. Opportunities for improving irrigation efficiency with quantitative models, soil water sensors and wireless technology. Journal of Agricultural Science, 2010; 148: 1–16.

[23] Riquelme J A, Soto F, Suardiaz J, Sanchez P, Iborra A, Vera J A. Wireless sensor networks for precision horticulture in Southern Spain. Computers and Electronics in Agriculture, 2009; 68(1): 25–35.

[24] Shukla S, Yu C Y, Hardin J D, Jaber F H. Wireless data acquisition and control systems for agricultural water management projects. Horttechnology, 2006; 16(4): 595–604.

[25] Gao F, Yu L, Zhang W A, Xu Q X, Yu L J. Research and design of crop water status monitoring system based on wireless sensor networks. Transactions of the CSAE, 2009; 25(2): 107–112. (in Chinese with English abstract)