# DESIGN OF AN INTELLIGENT IRRIGATION SYSTEM FOR A JUJUBE ORCHARD BASED ON IoT
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# *基于物联网的枣园智能灌溉系统设计*

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***Keywords:*** *IoT, smart irrigation, 4G network, human–computer interaction*

## ABSTRACT

*This research aimed to develop an information acquisition and intelligent irrigation decision system based on the agricultural Internet of Things (IoT). The system consists of a field control terminal and a remote client, realizing control, real-time display, alarm, and other functions. The user may apply the upper and lower limit of soil relative water content as the irrigation decision threshold. The system automatically controls irrigation according to the threshold. In the calculation and analysis part of the system, the programming software Keil 5 was used for data collection and monitoring, database comparison, calculation and analysis, irrigation decision, and other functions.*

## 摘要

*本研究旨在开发一套基于农业物联网的枣园信息获取与智能灌溉决策系统。该系统由现场控制终端和远程客户端组成，实现控制、实时显示、报警等功能。用户可将适宜枣树生长的根区土壤相对含水量上下限值作为灌溉决策的阈值，系统根据其阈值自动控制灌溉，该系统计算分析部分采用编程软件 Keil 5 来实现数据采集监测、模数转换、数据库对比、计算分析与灌溉决策等功能。*

## INTRODUCTION

There is a lack of water resources in the arid regions of western China. Additionally, existing water resources are unevenly distributed. Agricultural water consumption accounts for a total amount of 0.6 and the utilization rate is only about 0.4 *(Feng et al., 2018).* Further, traditional irrigation methods, such as flood irrigation, waste a lot of water and may negatively affect crop yield and quality *(Li et al., 2017).* Therefore, methods for efficient water saving are a regional research focus since the 1980s.

In recent years, the rapid development of Internet of Things (IoT) has brought the social development into the Era of the IoT. As the third wave of world information industry after the wave of computer and the internet, the IoT has penetrated into various industries and led a new trend of water-saving agriculture *(Han et al., 2017; Mason el al., 2019; Mendes et al., 2019; Yu et al., 2016; Jia et al., 2015).* In 2013, an intelligent crop water allocation method suitable for active irrigation scheme was proposed, and the results of the irrigation control model were compared with those of the classical irrigation control model. The results show that the fuzzy intelligent state descending (ISD) mechanism can produce appropriate irrigation control decisions *(Ganji et al., 2013).* At the same time, the energy saving and water saving effect and gross profit rate of intelligent sorghum surface drip irrigation were studied. Combined with new technology, total output and profit can be increased and resources can be fully utilized *(Papanikolaou et al., 2013).* In 2014, from the perspective of water saving and information collection, the idea of rotation irrigation improvement was designed to improve the response time of irrigation system and the security and reliability of irrigation system *(Li et al., 2014; Lv et al., 2014).* In 2018, combined with drip irrigation technology, the greenhouse automatic monitoring system was developed to monitor various plant growth parameters, optimize the utilization of agricultural water resources, and improve the water use efficiency of crop production *(Sivagami et al., 2018).* In 2019, an intelligent water-saving irrigation monitoring system based on LoRa technology was developed to improve agricultural irrigation efficiency and reduce water resource waste, combining automatic irrigation with water price reform to realize

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water-saving irrigation *(Song et al., 2019).* In addition, a low-cost intelligent irrigation system has been developed, which can be connected to devices connected to the Internet of Things. The main advantages of the system are intelligence, low cost and portability. Suitable for greenhouses and farms *(Nawandar et al., 2019).* With the development of science and technology, a set of sensor network acquisition system for automatic irrigation and fertilization has been developed, which can reduce water consumption by 74.92% *(Karunanithy et al., 2020).* Recently, a prototype of an efficient irrigation system composed of ARM microcontroller and GSM module has been developed, which can detect rainfall, inform farmers of rainfall levels and automatically adjust irrigation water quantity *(Barkunan et al., 2020).* At present, capacitive soil moisture sensor is often used to monitor soil moisture content in drip irrigation system. The difference between capacitive soil water sensor and traditional resistance soil moisture sensor is that it is not easy to be corroded *(Domínguez-Niño et al., 2020).*

In summary, current IoT irrigation control systems have achieved remarkable results in terms of intelligence and water saving. However, they still have some defects, such as weak remote and on-site integration performance, tedious human-computer interaction operation, and difficulties in secondary development. To more effectively implement precise irrigation, this study used a STM32F103ZET6 single-chip computer as the core control processor and a 4G module to connect the sensor system to the remote server. The current mature 4G network makes remote connections more rapid and stable. System design human-computer interaction interfaces enhance the scene of the remote and interactive, making monitoring and control more convenient and intuitive, and realizes the remote integration of field monitoring and control. This independent drip irrigation system implements real-time monitoring of soil temperature and relative water content, to provide technical support for the future of intelligent agriculture.

## MATERIALS AND METHODS

### *System architecture*

The system is divided into two plate assemblies, a field terminal, and a remote client. The system's overall framework is shown in Fig. 1, and its appearance is shown in Fig. 2.

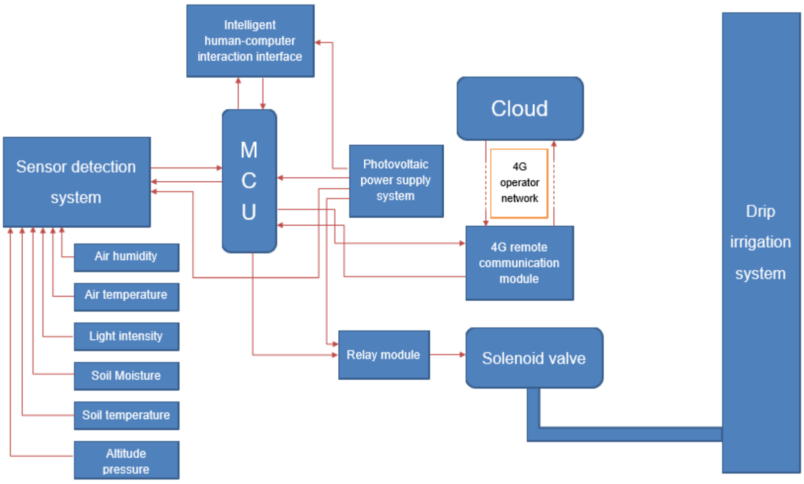


**Fig. 1 – Overall system architecture**

**Fig. 2 – Appearance**

The field control terminal comprises a core control system, a sensor monitoring system, a photovoltaic power supply system, an irrigation system, and a human-computer interaction interface. The core control system is composed of the STM32F103ZET6 microcontroller. This processor has become one of the most popular processors of the ARM company due to its low cost, fast operation speed, and rich interface. Our design adopts this chip as the core controller to achieve short time delays and high stability. The sensor system measures air temperature, relative humidity, atmospheric pressure, altitude, light, soil temperature, soil moisture, and other variables to monitor crop environmental information in real-time. The photovoltaic power supply system is composed of a solar panel, a constant voltage charger, and a new type of lead-acid battery, which can provide more stable outdoor power for the system and improve hardware life. The irrigation system is composed of a relay, a solenoid valve, and a drip irrigation system. An advanced indirect subsurface drip irrigation system is used to improve the water use efficiency. The human-computer interaction interface uses a serial touch screen. The HCI programming software was used to write the serial touch screen program, integrating control, real-time display, and alarm functions to ensure its practicability.

The remote client uses a 4G module to build the connection between the site and the remote. At present, the 4G network has been popularized worldwide, featuring high efficiency, strong flexibility, and good compatibility (*Tian et al., 2019).* This 4G module used for the data interaction is a WH–LTE–7 S4 V2, a pin type 4G module, with the function of UART turn 4G two-way passthrough 5 die 13 frequency, high speed, and low latency. It supports two online links at the same time and has support for TCP, UDP, a support registration mechanism/heartbeat package, support network passthrough mode, HTTPD, UDC, and a support basic instruction set. It supports FOTA difference for upgrades and stable operation. The system response speed and accuracy are much improved, and multi-terminal control is realized. The functional structure of the 4G module is shown in Fig. 3.

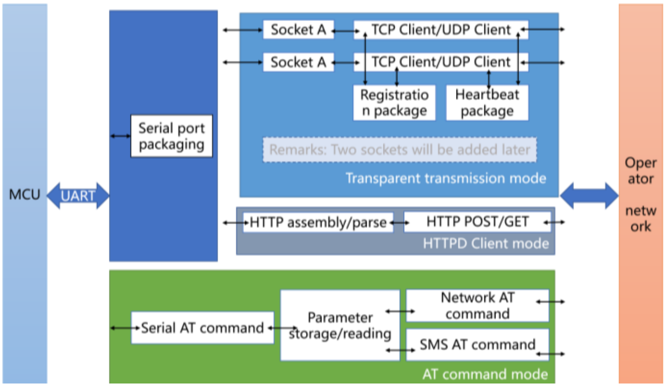


**Fig. 3 – 4G module functional structure**

***Principle of system operation***

The system field control terminal is divided into the acquisition and the control process. The system acquisition process collects data through the sensor system and sends the collected data to the core control system MCU, which processes the data. It sends it to the remote client and the human-computer interaction interface, which can display real-time data, system working status, charts, historical data, and alarm information. The system control process works as follows: when the system detects a water shortage signal in the crop root area, it sends the irrigation signal to the relay to control the solenoid valve to open for irrigation. When the irrigation amount reaches the upper limit of the set irrigation threshold, the system will stop irrigation and wait for the next water shortage. The system uses capacitive moisture sensors to measure soil relative water content. The sensor specifications are: 114 mm effective length, 19 mm width, 1.6 mm thickness. sensors have a large induction area, high precision, and high stability, to solve the problems of traditional sensors with small detection areas, and improve the accuracy of the response.

The remote client is divided into the PC terminal and mobile terminal, and the system remote client can realize remote data acquisition and control functions. The sensor acquisition system packages the acquired information through the MCU. It sends the packaged data to the remote client through the 4G module, thereby achieving efficient and orderly data exchange.

With the IoT system working principle as shown in Fig. 4, the sensor acquisition system connects through the I/O bus terminal with the control, human-computer interaction interface by the MCU UART connection site. Hereby data collected in the Modbus protocol are transmitted by 4G operators network transmission to the cloud server, and from the cloud server – via the Internet TCP/IP protocol to realize remote data conversion – to the mobile terminal and PC.

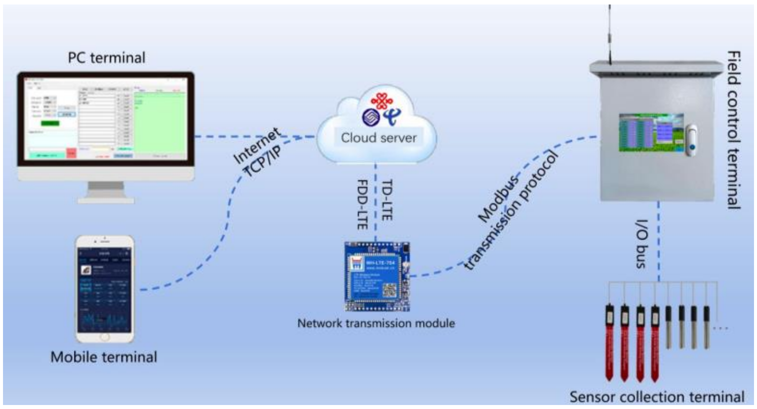


**Fig. 4 – Working principle of the IoT system**

### *Design of the core control system*

The core control system, also known as MCU, collects soil moisture, soil temperature, air temperature, relative humidity, light intensity, and other data in an orderly manner through the sensor. It completes A/D conversion through the A/D conversion unit in the MCU and sends it to the remote client and human-computer interaction interface after the completion of the A/D conversion, and automatically records and stores it. The stored historical data contains crop information of different periods. Users can execute queries in the form of a graph or download data in Excel format to the user's computer for crop data analysis.

### *Irrigation process*

First, the system is powered up and connected to the server. Second, the system can be run in manual mode and automatic mode. The default setting is the automatic mode that is used when the system uses crop root zone water information. The irrigation system alarm is transmitted by the bus transmission signal to the relay, and the relay controls the solenoid valve to open for irrigation. Then, the irrigation system sends a stop command after irrigation, waiting for the next irrigation cycle, and records the irrigation data at a time. The irrigation flow of the system is shown in Fig. 5.

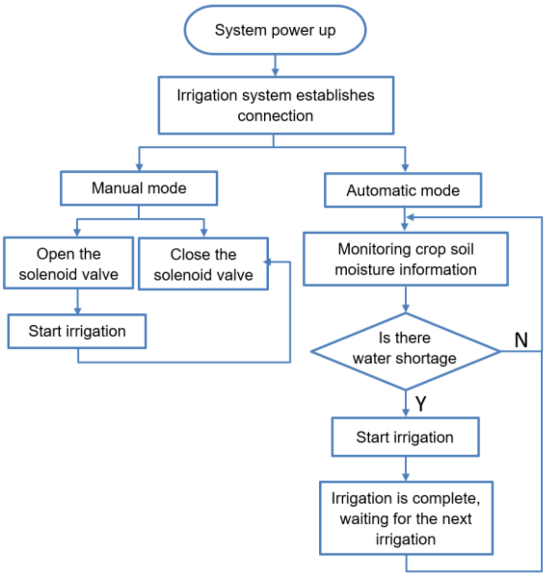
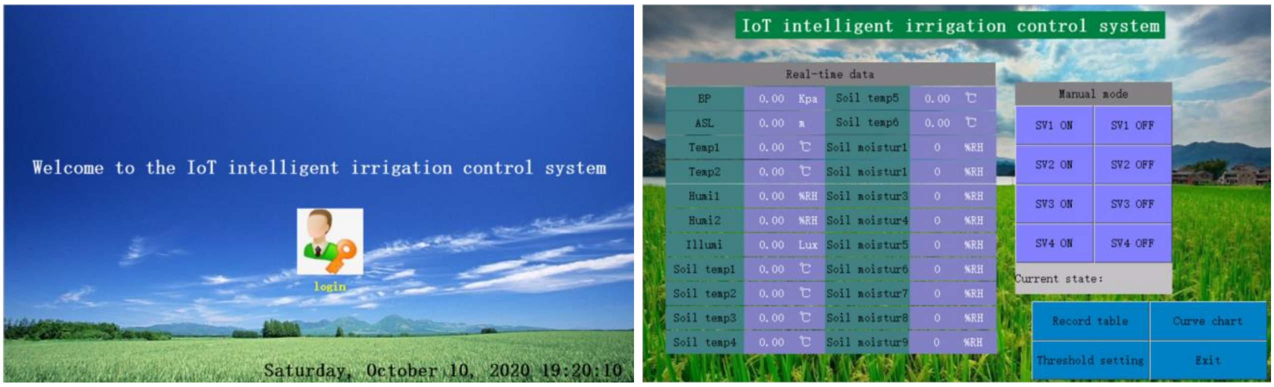


**Fig. 5 – System irrigation process**

### *Design of the human–computer interaction interface*

Traditional screen programming is challenging and difficult to redevelop, and screens with touch functions tend to be more expensive. Therefore, this system adopts an HCI serial port screen and a screen integration HCI statement. The basic idea of HCI is to send relevant commands and requirements through HCI to complete the execution work of relevant equipment *(Xu et al., 2020).* This function is convenient to realize, and the development is strong. Our initial interface is shown in Fig. 6a, and the main interface is shown in Fig. 6b. The human-computer interaction interface is designed for user login, real-time data display, graph display, irrigation record table, irrigation threshold setting, historical data record table, as well as other functions.


Welcome to the IoT intelligent irrigation control system

Saturday, October 10, 2020 19:20:10

Current state:

Real-time data

| | | | | | |
|---|---|---|---|---|---|
| BP | 0.00 | Kpa | Soil temp5 | 0.00 | ℃ |
| ASL | 0.00 | m | Soil temp6 | 0.00 | ℃ |
| Temp1 | 0.00 | ℃ | Soil moistur1 | 0 | %RH |
| Temp2 | 0.00 | ℃ | Soil moistur1 | 0 | %RH |
| Humi1 | 0.00 | %RH | Soil moistur3 | 0 | %RH |
| Humi2 | 0.00 | %RH | Soil moistur4 | 0 | %RH |
| Illumi | 0.00 | Lux | Soil moistur5 | 0 | %RH |
| Soil temp1 | 0.00 | ℃ | Soil moistur6 | 0 | %RH |
| Soil temp2 | 0.00 | ℃ | Soil moistur7 | 0 | %RH |
| Soil temp3 | 0.00 | ℃ | Soil moistur8 | 0 | %RH |
| Soil temp4 | 0.00 | ℃ | Soil moistur9 | 0 | %RH |

*a)* *b)*

**Fig. 6 – User interface**

*a) Initial; b) Main*

### *Photovoltaic power supply system*

Considering that the system is used in remote and challenging areas, a photovoltaic power supply system was designed. The power supply system provides stable voltage and current output with a strong anti-interference performance. The integrated board uses the new polysilicon solar panel, whose service life is long. It can be used with a variety of batteries. The system may use the new lead-acid battery, ABS shell, and a lead-calcium-alloy grid that has a long service life, stable power supply, and high safety characteristics. The photovoltaic power supply system is shown in Fig. 7.

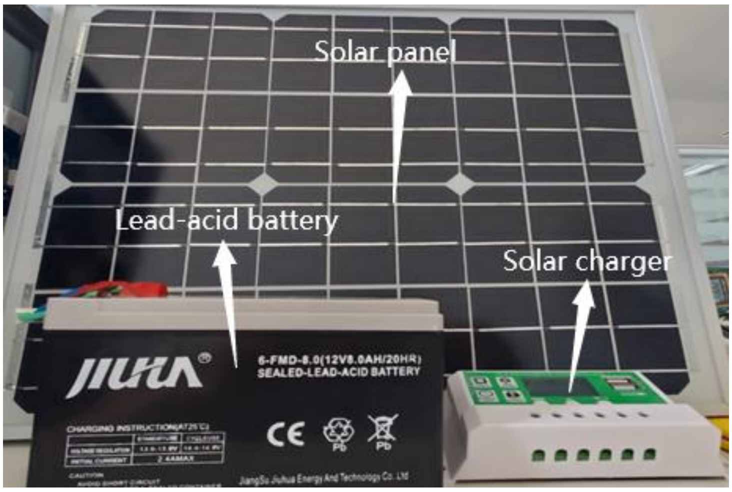
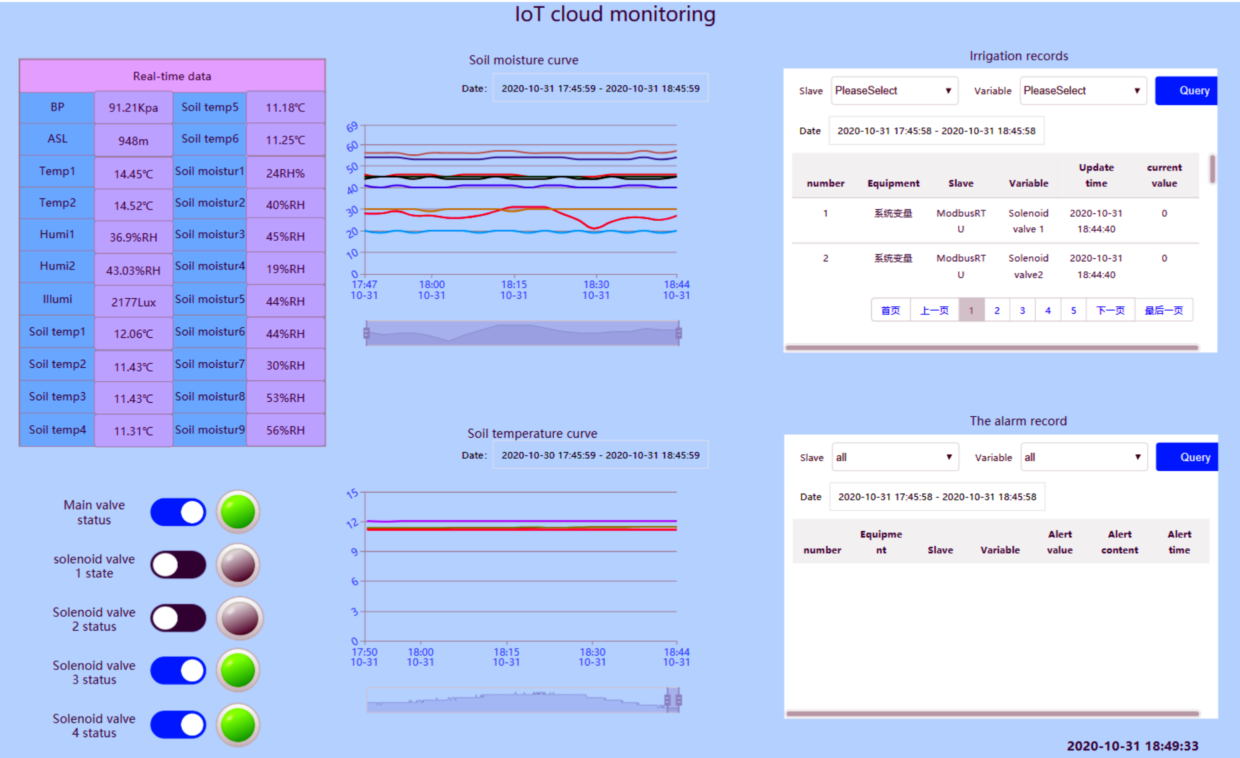


**Fig. 7 – Photovoltaic power supply system**

### *Remote control system design*

To facilitate the software design, this system adopts the business's cloud programming system, which avoids challenges with APP software development. The monitoring interface of the remote PC terminal is shown in Fig. 8, and that of the mobile terminal is shown in Fig. 9. The configuration interface between the remote PC monitoring terminal and the mobile monitoring terminal is designed. The PC terminal displays real-time crop information, alarm information, and historical data through the cloud monitoring large screen. The mobile terminal mainly guarantees the simplicity of mobile operation and realizes status display, real-time data display, alarm, etc.



IoT cloud monitoring

Real-time data

| | | | |
|---|---|---|---|
| BP | 91.21Kpa | Soil temp5 | 11.18℃ |
| ASL | 948m | Soil temp6 | 11.25℃ |
| Temp1 | 14.45℃ | Soil moistur1 | 24RH% |
| Temp2 | 14.52℃ | Soil moistur2 | 40%RH |
| Humi1 | 36.9%RH | Soil moistur3 | 45%RH |
| Humi2 | 43.03%RH | Soil moistur4 | 19%RH |
| Illumi | 2177Lux | Soil moistur5 | 44%RH |
| Soil temp1 | 12.06℃ | Soil moistur6 | 44%RH |
| Soil temp2 | 11.43℃ | Soil moistur7 | 30%RH |
| Soil temp3 | 11.43℃ | Soil moistur8 | 53%RH |
| Soil temp4 | 11.31℃ | Soil moistur9 | 56%RH |

Soil moisture curve
Date: 2020-10-31 17:45:59 - 2020-10-31 18:45:59

Soil temperature curve
Date: 2020-10-30 17:45:59 - 2020-10-31 18:45:59

Irrigation records
Slave: PleaseSelect
Variable: PleaseSelect
Date: 2020-10-31 17:45:58 - 2020-10-31 18:45:58

| number | Equipment | Slave | Variable | Update time | current value |
|---|---|---|---|---|---|
| 1 | 系统变量 | ModbusRTU | Solenoid valve 1 | 2020-10-31 18:44:40 | 0 |
| 2 | 系统变量 | ModbusRTU | Solenoid valve2 | 2020-10-31 18:44:40 | 0 |

The alarm record
Slave: all
Variable: all
Date: 2020-10-31 17:45:58 - 2020-10-31 18:45:58

| number | Equipment | Slave | Variable | Alert value | Alert content | Alert time |
|---|---|---|---|---|---|---|

2020-10-31 18:49:33

**Fig. 8 – Remote PC monitoring interface**

IoT Cloud Monitoring-Mobile terminal

| Real-time data | | | |
|---|---|---|---|
| BP | 91.24Kpa | Soil temp5 | 11.25℃ |
| ASL | 944m | Soil temp6 | 11.43℃ |
| Temp1 | 9.1℃ | Soil moistur1 | 30RH% |
| Temp2 | 9.21℃ | Soilmoistur2 | 41%RH |
| Humi1 | 52.36%RH | Soil moistur3 | 46%RH |
| Humi2 | 59.55%RH | Soil moistur4 | 20%RH |
| Illumi | 50Lux | Soil moistur5 | 45%RH |
| Soil temp1 | 12.12℃ | Soil moistur6 | 45%RH |
| Soil temp2 | 11.62℃ | Soil moistur7 | 30%RH |
| Soil temp3 | 11.56℃ | Soil moistur8 | 54%RH |
| Soil temp4 | 11.56℃ | Soil moistur9 | 56%RH |

Main valve status ○
solenoid valve 1 state ○
solenoid valve 2 state ○
solenoid valve 3 state ●
solenoid valve 4 state ●

2020-10-31 19:44:42

| | |
|---|---|
| 53.48 | 2020-10-31 19:44:41 |
| 52.36 | 2020-10-31 19:41:42 |
| 51.04 | 2020-10-31 19:38:42 |
| 51.19 | 2020-10-31 19:35:42 |
| 50.22 | 2020-10-31 19:32:44 |

1 /5

**Fig. 9 – Mobile monitoring interface**

### *Programming*

The calculation and analysis part of the system is implemented in the C language, and the programming software is Keil 5. Data acquisition and monitoring, analog-digital conversion, database comparison, calculation and analysis, irrigation decision-making, and other functions were programmed. Example programs are shown in Fig. 10.

```c
unsigned int  Get_Adc(unsigned char ch)
{

  ADC_RegularChannelConfig(ADC1,ch,1, ADC_SampleTime_239Cycles5);

  ADC_SoftwareStartConvCmd(ADC1,ENABLE);

  while(!ADC_GetFlagStatus(ADC1,ADC_FLAG_EOC));

  return ADC_GetConversionValue(ADC1);
}
unsigned int Get_Adc_Data(unsigned char ch)
{
unsigned int addat,res;
addat=Get_Adc(ch)>>4  ;
      if(addat<35)
        res=100;
      if(addat>=222)
        res=0;
      if(addat>= 35 && addat<58)
        {res=100 - 20*(addat-35)/(58-35);}
      if(addat>= 58 && addat<85)
        {res=80- 20*( addat-58)/(85-58);}
      if(addat>= 85 && addat<137)
        {res=60-20*( addat-85)/(137-85);}
      if(addat>= 137 && addat<178)
        {res=40-20*( addat-137)/(178-137);}
      if(addat>= 178 && addat<222)
        {res=20-20*( addat-178)/(222-178);}
          return res;
      }

```

***a)***

```c
if(ucRegCoilsBuf[4]==1)
{
if(ucRegCoilsBuf[0]==1)
{GPIO_SetBits(GPIOG,GPIO_Pin_2);
}
else if(ucRegCoilsBuf[0]==0)
{GPIO_ResetBits(GPIOG,GPIO_Pin_2);
}

if(ucRegCoilsBuf[1]==1)
{GPIO_SetBits(GPIOG,GPIO_Pin_3);
}
else if(ucRegCoilsBuf[1]==0)
{GPIO_ResetBits(GPIOG,GPIO_Pin_3);
}

if(ucRegCoilsBuf[2]==1)
{GPIO_SetBits(GPIOG,GPIO_Pin_4);
}
else if(ucRegCoilsBuf[2]==0)
{GPIO_ResetBits(GPIOG,GPIO_Pin_4);
}

if(ucRegCoilsBuf[3]==1)
{GPIO_SetBits(GPIOG,GPIO_Pin_5);
}
else if(ucRegCoilsBuf[3]==0)
{GPIO_ResetBits(GPIOG,GPIO_Pin_5);
}
}
```

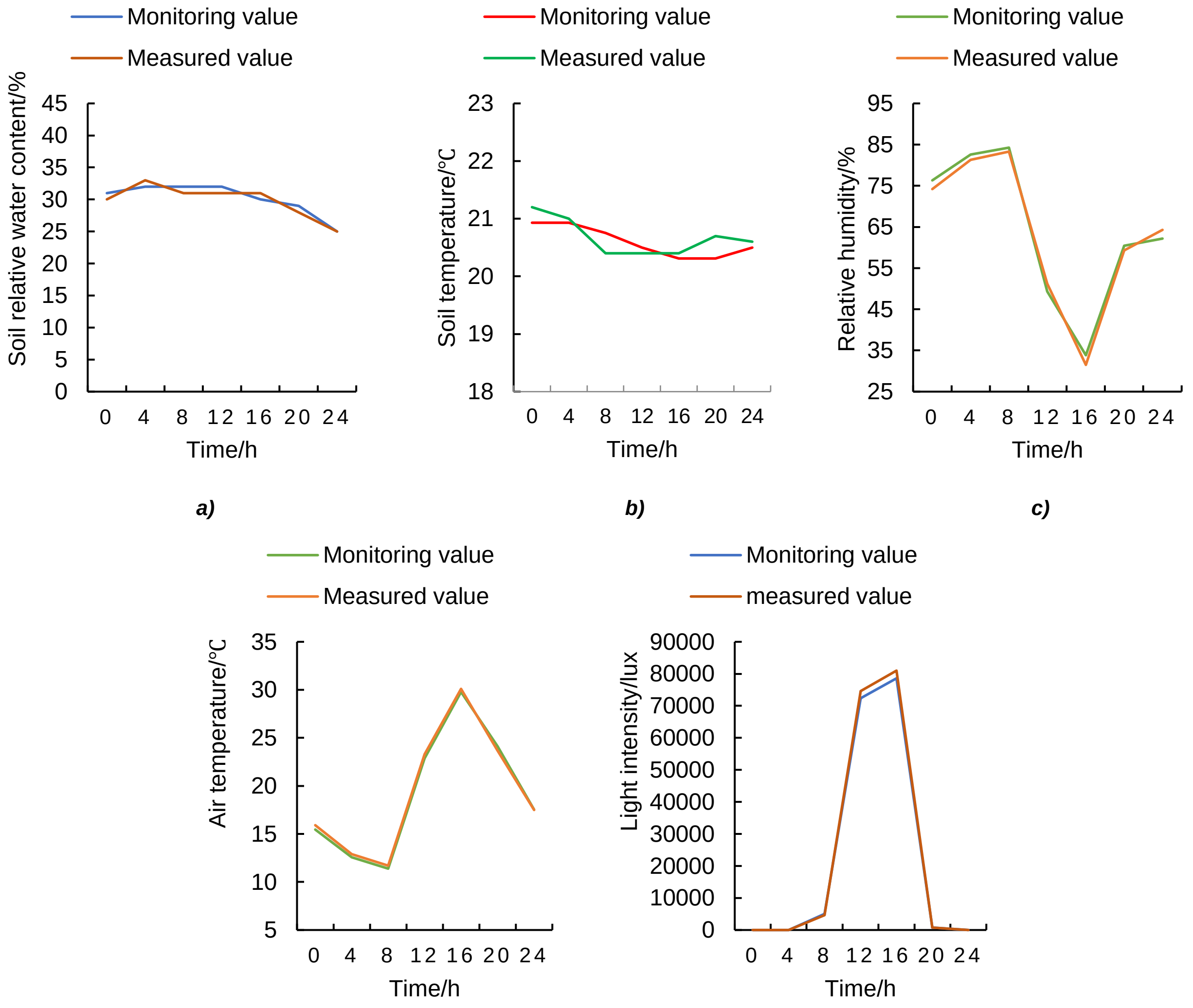
***b)***

**Fig. 10 – A part of the program:**
*a) Water collection; b) Automatic irrigation*

## RESULTS

### *System accuracy test*

The system was tested at the water-saving irrigation test base of the Tarim University in Aral, Xinjiang Province, China, and the following functions were verified: air temperature, relative humidity, soil relative water content, soil temperature, and light intensity. The system used the Chinese sea library union HKSHC03S soil moisture sensor that measures soil relative water content (± 2% accuracy), the Dallas DS18B20 digital temperature sensor (± 0.5°C), the Swiss sensirion SHT31 air temperature and humidity sensor (± 0.3 °C) for temperature, ± 2% for relative humidity). A US american Max44009 digital ambient light sensor (maximum gain error of 15%) was used to measure the light intensity in the Jujube orchard. We used the following instruments to assess the accuracy of the system and we ensured that the measuring instruments and the measurement system was at the same position of the sensors at the same time: the Chinese Ji Tai FD–T soil moisture meter (± 0.5% accuracy), the Chinese Huashengchang DT-321S temperature and humidity meter (temperature accuracy of ± 0.5 °C), relative humidity accuracy of ± 2%), and the Chinese Taiwan's Tai Shi TES1330A light intensity tester (± 0.5% FS precision). System data accuracy tests are shown in Fig. 11.



*a)* *b)* *c)*

*d)* *e)*

**Fig. 11 – Monitored values of the information acquisition module and the measured values of the instrument on September 13, 2020**

In the test data in Fig. 11, sensor and instrument data were in good agreement. Relative errors were within ± 3% for relative humidity. Soil temperature and air temperature relative errors were within ± 0.5℃. Light intensity relative errors were within ± 10% and show that the sensor monitoring values were more accurate and stable.

### *Intelligent irrigation accuracy test*

The tested crops were jujube trees in the mature stage. The IoT monitoring system was set for irrigation, and indirect underground drip irrigation technology was adopted *(Sun et al., 2016).* According to Xu Rong et al., two groups of repeated experiments were set to 14 d test system. Research shows that dwarf close planting jujube under subsurface drip irrigation is indirect, with the water content of the soil in a maximum of 15 ~ 30 cm. Therefore, the soil moisture sensors are embedded in a depth of 10 cm, 25 cm, and 40 cm *(Xu et al., 2014).* The soil temperature sensors are buried in 15 cm and 25 cm depth, and 10 cm away from the trunk. Under the condition of highest water use efficiency, the soil water content in a 10 ~ 40cm soil layer change range is about 7% ~ 14% (dry soil weight %). Since the soil moisture sensor's measured value is the relative water content of soil, the volumetric water content of soil should be obtained first to obtain the soil's relative water content. The formula of the volumetric water content of the soil is:

$$\theta_{\omega} = \frac{\rho_d}{\rho_{\omega}} \cdot \omega \tag{1}$$

where:

$\theta_{\omega}$ is the volumetric soil water content, [%]; $\rho_d$ is the dry density, [g/cm³]; $\rho_{\omega}$ is the soil water density, [g/cm³]; ω is the soil weight water content, [%]. The calculated soil volumetric water content varied from 9.8% to 19.6%. The formula of soil relative water content is:

$$\text{Relative water content of dryland soil (\%)} = \text{soil water content/field water holding capacity} \times 100 \tag{2}$$

The soil surface texture of the Jujube orchard was sandy loam, the soil density was 1.42g/cm$^3$, and the field water holding rate was 29.1% (volume) *(Ye et al., 2012).* After conversion, the soil water content was 34%~72% (% of the soil mass), and this threshold was set for autonomous irrigation. The system irrigation test is shown in Table 1, and the change curve of soil relative water content is shown in Fig. 12.

**Table 1**

**System irrigation tests**

| Test type | Date | Threshold set up [%] | Irrigation interval [d] | Irrigation trigger value of soil relative water content [%] | Irrigation stop value of soil relative water content [%] | Whether irrigation is completed | Whether to send manual irrigation instructions | Whether to alarm |
|---|---|---|---|---|---|---|---|---|
| Automatic irrigation test | September 11, 2020 | 34%~72 | 0 | ≤33~34 | ≥72~73 | Yes | No | No |
| | September 15, 2020 | | 3 | ≤33~34 | ≥72~73 | Yes | No | No |
| | September 19, 2020 | | 3 | ≤33~34 | ≥72 | Yes | No | No |
| Manual irrigation test | September 20, 2020 | | | | | Yes | Yes | No |

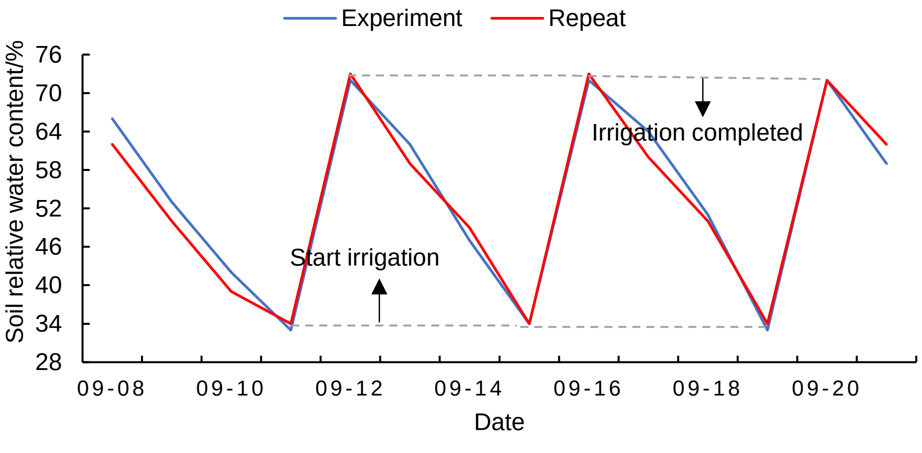


**Fig. 12 – Soil relative water content change curve**

According to Table 1, the system can report the completion and alarm information of irrigation in real-time while automatically irrigating using the set irrigation threshold. Manual control can be effectively implemented without conflicts with the automatic irrigation. As shown in Fig. 12, when the soil water content was lower than 34%, the system automatically irrigated when it alarmed. When it was higher than 72%, the system stopped irrigation, indicating that it could carry out stable irrigation according to the set water content.

## CONCLUSIONS

Using IoT and HCI technology, we designed an intelligent irrigation system of a Jujube orchard, which realized the integration of remote monitoring and field monitoring and increased the diversity of intelligent irrigation system monitoring. During our experiment in the Jujube orchard air temperature, relative humidity, illumination, and soil water content was monitored in real-time. Accuracy tests showed that the data this system produced during the monitoring process were realistic and associated with low measurement uncertainties. Intelligent irrigation could be realized automatically and timely by setting an irrigation threshold according to soil water content change in the crop root area. Finally, our work provides a technical and theoretical basis for the intelligent irrigation of other crops.

## ACKNOWLEDGEMENT

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