Design of a greenhouse remote measurement and control system based on internet of things technology

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Abstract. This study designed a greenhouse remote measurement and control system based on Internet of Things technology. The system is based on WebOP Designer configuration software and Modbus communication protocol, with Adam4060 relay output module and intermediate relay as the control core. Remote monitoring of the greenhouse environment is achieved through cooperation with the greenhouse environmental data acquisition sensor, the Adam-4117 analog input module, the industrial-grade programmable human-machine interface, the internet/intranet and the Web Access web database. Local customers can view real-time data and historical curves by operating the human-machine interface, and control the operation of each actuator in the greenhouse according to the alarm status and warning line settings. The remote client can log in to the webpage database through the PC client and the mobile client conveniently and quickly. The system is beneficial to reduce labor costs and improve the informationization level and management efficiency of agricultural production. Through the access of expert systems, precise control of crop growth environment is achieved, and the economic benefits of crops are improved.

1. Introduction

In recent years, China's greenhouse industry has developed by leaps and bounds, and a complete technical system is gradually being established. Due to the lack of facilities environment-crop interaction mechanism and poor facilities-equipment matching, China's greenhouse system still has a large gap with the international advanced level in terms of stability and intelligence, which restricts the promotion of industrial benefit level and labor productivity [1, 2]. Due to the low level of knowledge and culture of farmers, the understanding of modern agricultural production technology is not complete. There are still many greenhouse industries in rural areas that are still regulated by manual management and require a lot of manpower and material resources. Not only does it cause waste of energy, but the economic benefits of crops are difficult to guarantee [3-5].

The "Internet of Things" (IoT) is a highly promising family of technologies which is capable of offering many solutions towards the modernisation of agriculture. Scientific groups and research institutions, as well as the industry, are in a race trying to deliver more and more IoT products to the agricultural business stakeholders, and, eventually, lay the foundations to have a clear role when IoT becomes a mainstream technology [6]. With the maturity of the Internet of Things technology, it is widely used in the greenhouse industry [7]. X L Jiang et al. use two-line decoding technology and
cloud computing to scientifically analyze irrigation water and fertilizer, which can meet the demand of water and fertilizer for crops growth under different environmental conditions, and realize intelligent control of water and fertilizer integration. Accurately realize the efficient water-saving irrigation of water and fertilizer integration, and promote the development of agricultural modernization [8]. BY Wang et al. designed a greenhouse remote monitor based on STMA32F103ZET6 microcontroller. Through the Wi-Fi module, the environment parameters of the sensing nodes in 1~5 greenhouses were collected and uploaded to the cloud server to remotely monitor multiple greenhouse environment parameters [9]. WB Zhao et al. proposed a solution for IoT greenhouse information management system with Zigbee wireless sensing, WIFI wireless communication and industrial Ethernet. Using this system to collect and process large and multi-type data information such as crop information, environmental information, and control information [10]. However, compared with wired communication, Zigbee wireless sensing and WIFI wireless communication can connect fewer nodes, and are susceptible to interference and maintenance in complex environments. HY Wang et al. detailed design of the intelligent greenhouse infrastructure, covering materials, ventilation system and insulation system, and the addition of the terminal access layer in the three-layer model of the networking standard, to achieve intelligent sensing and remote control of agricultural greenhouses [11]. This study provides a reference for the design of this system. RH Liang et al. used computer technology and Internet of Things technology to build a greenhouse intelligent management system, through the computer's WEB page to achieve data collection, network monitoring, big data analysis, device control and other functions [12]. The disadvantage of this system is that there is no local client and it is not possible to directly view the greenhouse node parameters.

Based on the research results of predecessors and the needs of China's rural greenhouse industry, it is easy to operate and maintain the current situation of greenhouse remote measurement and control system. Based on the Internet of Things technology, this paper designs a WebOP Designer configuration software and Modbus communication protocol. The Adam4060 relay output module and intermediate relay are the greenhouse remote measurement and control system for the control core. The system is suitable for both the single-family greenhouse industry and the greenhouse industry. Compared with previous studies [9-12], this system is characterized by friendly human-computer interaction, intuitive interface, easy to understand, simple operation, easy maintenance, and easy to be accepted by farmers.

2. Overall system design

Real-time remote measurement and control of environmental parameters in the greenhouse (air temperature and humidity, soil temperature and humidity, CO2 concentration, light intensity) is a key technology in greenhouse production. The greenhouse remote measurement and control system designed in this study consists of a greenhouse remote measurement and control system based on WebOP Designer configuration software and Modbus protocol. The environmental parameter sensing node in the temperature chamber uploads the collected environmental parameters to the industrial-level programmable human-machine interface through the Adam-4117 analog input module. The human-machine interface visually displays and stores the data, and determining whether the environmental parameter exceeds a threshold according to a program that is programmed to be implanted. Whether the parameter exceeds the threshold, the command is sent to the Adam-4060 relay output module to control the operation of the environmental conditioning actuator in the greenhouse. At the same time, the human-machine interface uploads data to the Web Access database through the internet/intranet for users to access. Real-time monitoring of environmental parameters in greenhouses, centralized management of all monitoring nodes, remote transmission and storage of monitoring data, monitoring of system parameters and remote control. The user can adjust the warning threshold of the environmental parameters according to the expert system to achieve the good environment required for plant growth. The overall framework of the system is shown in Figure 1.
3. System hardware design
The system hardware is mainly composed of monitoring equipment and controller. The block diagram of the hardware system is shown in Figure 2.

![Figure 2. Hardware system block diagram.](image-url)
3.1. Sensor selection
The sensing layer is composed of various sensors to realize real-time monitoring of air CO2 concentration, air temperature and humidity, soil moisture and light intensity. Sensor selection determines the accuracy of the system measurement data and is the key to the system. After multi-brand sensor test comparison, the sensor used in this system is 4~20mA current analog output, and the environmental parameter value is obtained according to the magnitude and change of the current value. The current analog output is less susceptible to interference than the voltage output, because the amplitude of the noise voltage in the industrial field may reach several V, but the power of the noise is very weak, so the noise current is usually less than the nA level, and the internal resistance of the current source tends to infinity. The series connection of the wire resistance does not affect the accuracy in the loop, so the error caused by the 4~20 mA transmission is very small. After comparing and testing various types of sensors, the final sensor parameters are shown in Table 1.

Table 1. Sensor selection.

| Sensor                        | Number | Range                  | Accuracy                              |
|-------------------------------|--------|------------------------|---------------------------------------|
| Air temperature and humidity sensor | 2      | Temperature -40°C~+80°C | ±0.3°C(25°C)                          |
|                               |        | Humidity 0% ~100%RH    | ±2%RH                                 |
| Soil temperature and humidity sensor | 1      | Temperature -40°C~+80°C | ±0.5°C(25°C)                          |
|                               |        | Humidity 0% ~100%RH    | ±3%RH                                 |
| Light intensity sensor        | 1      | 0~65535Lux             | ±7%                                   |
| CO2 concentration sensor      | 1      | 0~5000PPM              | ±(50PPM+3% reading)(25°C)            |

3.2. Node parameter acquisition and display
The data acquisition and equipment control of this system adopts ADAM-4000 series modules. The ADAM-4117 is an 8-channel analog input module with independent differential channels. It is mainly used to collect analog input signals such as temperature, humidity, CO2 concentration and illumination intensity. The number of channels meets the requirements of this system. The sensor is connected to the WOP-2070T industrial-grade human-machine interface via the ADAM-4117, using serial transmission and Modbus protocol. The sensor sends the collected data to Adam-4117 and outputs 4~20mA analog quantity. After RS-232 communication, the analog quantity is converted into the corresponding hexadecimal positive integer 0~65535, which is set in the Wop-2070T man-

Table 2. Sensor acquisition data conversion formula.

| Environmental parameters | Conversion formula |
|--------------------------|--------------------|
| Air temperature (°C)     | $T_1=7.5*I_1-70$   |
| Air humidity (%RH)       | $HR_1=6.25*I_2-25$ |
| Soil temperature (°C)    | $T_3=7.5*I_3-70$   |
| Soil water content (%RH) | $HR_2=6.25*I_4-25$ |
| CO2 Concentration (PPM)  | $CO_2=312.5*I_5-1250$ |
| Light intensity (Lux)    | $LX=65535/16*I_6-16383.75$ |
machine interface. Zooming converts 0~65535 to decimal data. After calculation, the conversion formula of each sensor acquisition data is shown in Table 2. ADAM-4060 is a 4-way relay output module, 2-way A-type, 2-way C-type, equipped with the corresponding peripheral interface circuit, which satisfies the value and action. In order to control the temperature and humidity, the system is equipped with a relay interface board for controlling electromechanical devices such as solenoid valves, fans, solar machines, and roller shutter motors. The ADAM-4000 series modules are parameterized by the ADAM-4000-5000 utility program. The parameter settings of the Adam-4117 analog input module are shown in Figure 3.

![Figure 3. Adam-4117 analog input module settings.](image)

3.3. Hardware platform construction
The platform divides the hardware into two parts: an electrical control box and an external device. The external device is connected to the electrical control box via a pluggable waterproof connector. Flexible installation and removal of sensor devices. For places with a long transmission distance, a shielded signal line of appropriate length can be added between the sensor and the electrical control box. The electric control box includes 24V rectification power supply, man-machine interface, Adam-4117, Adam-4060 and other major electronic equipment. External equipment includes sensors, solenoid valves, fans, solar machines, roller blind motors, and more. The rectangular body waterproof and insulated plastic case with the outer casing size of 35cm*25cm*11cm is processed and processed. The opening is a waterproof joint with a cover, and the corresponding electronic components are connected inside. After testing, the electric control box has a waterproof rating equivalent to IP67, which can effectively protect the components in the box from sand and rain. The hardware device is shown in Figure 4.

Considering the network transmission rate, image quality, cost and other factors, the video surveillance equipment uses a webcam with a resolution of 720P. The video signal is transmitted through the industrial-grade router on the greenhouse, and the monitoring screen is embedded in the WebAccess page to facilitate the remote client to view the condition of the crop in the greenhouse. Users can also log in to the independent video surveillance system to view it by using the PC or mobile phone. The video monitoring device is shown in Figure 5.
4. System software design

4.1. Selection of design tools
The development software selects the WebOP Designer V2.0 configuration software, which is a powerful and intuitive software that can create a complete solution for the WebOP series of human-machine interface products. WebOP Designer V2.0 has been recognized by the application field and is an integrated development tool for simple applications. Multi-language version of Windows fonts, menus, alarms, data logging and slave logging, plus online and offline emulation, data transfer assistants, menu editors and text editors for user programming. Great convenience. The WebOP series
man-machine interface benefits from the good design of the WebOP Designer V2.0 configuration software during operation, ensuring the stability of the system operation and the good performance of the WebOP series human-machine interface, realizing the seconds switching of the screen, realizing Uninterrupted operation around the clock.

4.2. System software design
The software design includes human-machine interface design and background database design. The system software framework is shown in Figure 6.

![System Software Framework](image)

**Figure 6.** System software framework.

4.2.1. Human machine interface design. The system divides the man-machine interface display into system home page, real-time monitoring interface, temperature data and curve, humidity data and curve, CO2 concentration data and curve, light intensity data and curve, automatic control interface, system parameter setting interface and so on. The system home page is the initialization interface displayed after the system is powered on, which can play the role of beauty and prevent accidental touch. The real-time monitoring interface displays the environmental parameters of the sensing node in real time, and the sensing interval of the sensing node is 5 seconds/time, realizing the function of real-time monitoring. The functions of temperature, humidity, CO2 concentration, light intensity historical data and curve interface are to view historical data and historical curves, which can visually display changes in environmental parameters. The automatic control interface can view the operation status of each control device and set the threshold. It is also possible to artificially intervene the switches of each device. The system parameter setting interface realizes parameter setting of the man-machine interface, such as screen correction, system restart, brightness adjustment, history recording and the like. The real-time monitoring interface is shown in Figure 7. The historical data and curve interface is shown in Figure 8. The automatic control interface is shown in Figure 9.
Figure 7. Real-time monitoring interface.

Figure 8. Historical data and curve interface.
Figure 9. Automatic control interface.

The program setup code is as follows:

SU10 = W2F(0\textquotesingle 40001)  
* Convert the number in \textquotesingle 0\textquotesingle 40001 to a 32-bit floating point number and save it in SU10*

SU40 = SU10*16/65535+4(F)  
* T1 Convert floating point numbers to actual current values, saved in SU40*

SU72 = SU10*120/65535-40(F)  
* Convert floating point numbers to -40°C ~ 80°C and save in SU72*

SU14 = W2F(0\textquotesingle 40002)  
* Convert the number in \textquotesingle 0\textquotesingle 40002 to a 32-bit floating point number and save it in SU14*

SU44 = SU14*16/65535+4(F)  
* T2 Convert floating point numbers to actual current values, saved in SU44*

SU76 = SU14*120/65535-40(F)  
* Convert floating point numbers to -40°C ~ 80°C and save in SU76*

SU18 = W2F(0\textquotesingle 40003)  
* Convert the number in \textquotesingle 0\textquotesingle 40003 to a 32-bit floating point number and save it in SU18*

SU48 = SU18*16/65535+4(F)  
* H1 Convert floating point numbers to actual current values, saved in SU48*

SU80 = SU18*100/65535(F)  
* Convert floating point numbers to 0%RH-100%RH and save in SU80*

SU22 = W2F(0\textquotesingle 40004)  
* Convert the number in \textquotesingle 0\textquotesingle 40004 to a 32-bit floating point number and save it in SU22*

SU52 = SU22*16/65535+4(F)  
* H2 Convert floating point numbers to actual current values, saved in SU52*

SU84 = SU22*100/65535(F)  
* Convert floating point numbers to 0%RH-100%RH and save in SU84*

SU26 = W2F(0\textquotesingle 40005)  
* Convert the number in \textquotesingle 0\textquotesingle 40005 to a 32-bit floating point number and save it in SU26*
$U_{56} = U_{26} \times 16/65535 + 4 (F)$  \hspace{1cm} \text{T3 Convert floating point numbers to actual current values, saved in $U_{56}$*}

$U_{88} = U_{26} \times 120/65535 - 40 (F)$  \hspace{1cm} \text{Convert floating point numbers to -40°C ~ 80°C and save in $U_{88}$*}

$U_{30} = W2F(0\:40006)$  \hspace{1cm} \text{Convert the number in 0\:40006 to a 32-bit floating point number and save it in $U_{30}$*}

$U_{60} = U_{30} \times 16/65535 + 4 (F)$  \hspace{1cm} \text{H3 Convert floating point numbers to actual current values, saved in $U_{60}$*}

$U_{92} = U_{30} \times 100/65535 (F)$  \hspace{1cm} \text{Convert floating point numbers to 0%RH~100%RH and save in $U_{92}$*}

$U_{34} = W2F(0\:40007)$  \hspace{1cm} \text{Convert the number in 0\:40007 to a 32-bit floating point number and save it in $U_{34}$*}

$U_{64} = U_{34} \times 16/65535 + 4 (F)$  \hspace{1cm} \text{CO₂ Convert floating point numbers to actual current values, saved in $U_{64}$*}

$U_{96} = U_{34} \times 5000/65535 (F)$  \hspace{1cm} \text{Convert floating point numbers to 0~5000PPM and save in $U_{96}$*}

$U_{38} = W2F(0\:40008)$  \hspace{1cm} \text{CO₂ Convert the number in 0\:40008 to a 32-bit floating point number and save it in $U_{38}$*}

$U_{68} = U_{38} \times 16/65535 + 4 (F)$  \hspace{1cm} \text{LX Convert floating point numbers to actual current values, saved in $U_{68}$*}

$U_{100} = U_{68} \times 1$  \hspace{1cm} \text{The light intensity range is 0~65535Lux, which is consistent with the floating point range, and is scaled to 1*}

\begin{verbatim}
IF $U_{72}>0\:T1$ temperature upper limit (F)  \hspace{1cm} \text{Logically, when the $U_{72}$ data is greater than the set upper limit*}
3\:0\:DO0 = 1d(B)  \hspace{1cm} \text{3\:0\:DO0 (That is the 0001 channel of the Adam4060) Contact suction *}
ENDIF

IF $U_{72}<0\:T1$ temperature lower limit (F)  \hspace{1cm} \text{Logical judgment, when the $U_{72}$ data is less than the set lower limit*}
3\:0\:DO0 = 0d(B)  \hspace{1cm} \text{3\:0\:DO0 (That is the 0001 channel of the Adam4060) Contact disconnection*}
ENDIF

IF $U_{72}>0$ \hspace{1cm} \text{Buzzer start (F)}  \hspace{1cm} \text{Logically, when the $U_{72}$ data is greater than the set upper limit*}
3\:0\:DO1 = 1d(B)  \hspace{1cm} \text{3\:0\:DO1 (That is the 0002 channel of the Adam4060) Contact suotion*}
ENDIF

IF $U_{72}<0$ \hspace{1cm} \text{Buzzer stop (F)}  \hspace{1cm} \text{Logically, when the $U_{72}$ data is less than the set upper limit *}
3\:0\:DO1 = 0d(B)  \hspace{1cm} \text{3\:0\:DO0 (That is the 0002 channel of the Adam4060) Contact disconnection*}
ENDIF
END
\end{verbatim}

4.2.2. Network database design. The design of the network database consists of six steps, which are respectively divided into the establishment of engineering nodes, establishment of monitoring nodes, establishment of communication ports, establishment of equipment, establishment of I/O points and engineering design. To set up an engineering node, you need to set the IP address of the engineering node, other remote access codes, and so on. The core and difficulty of database design is to establish a communication port, and realize the remote measurement and control function of the greenhouse.
remote measurement and control system by setting the communication port. Finally, the remote management interface is shown in Figure 10.

5. Experimental result
In order to verify the function and stability of the greenhouse remote measurement and control system, a pilot study was conducted in the No. 12 greenhouse of Shenyang Agricultural University. The greenhouse is a strawberry cultivation greenhouse. The strawberry likes a cool climate. The strawberry root growth temperature is 5~30°C, the suitable temperature is 15~22°C, the stem and leaf growth temperature is 20~30°C, and the bud is frozen at -15~10°C. The temperature during the differentiation period must be maintained at 5~15°C, and the flowering result period is 4~40°C. The east-west direction of the greenhouse, the front slope and the back slope are steel-integrated semi-arched truss structures. The north wall adopts a composite wall of 0.12m brick wall +0.05m perlite thermal insulation material +0.37m brick wall, and the translucent surface covering material is a 0.8mm thick polyvinyl chloride film. The parameters of the solar greenhouse are shown in Table 3.

| Length (m) | Net span (m) | Ridge height (m) | Rear wall height (m) | Back slope elevation (°) | Back wall thickness (m) | Bottom vent length (m) | Bottom vent height (m) |
|------------|--------------|-----------------|----------------------|------------------------|------------------------|------------------------|------------------------|
| 60         | 8            | 3.95            | 2.7                  | 36                     | 0.54                   | 60                     | 0.1                    |

The test period is from March 3, 2018 to March 31, 2018. The system is powered by a 24V regulated DC power supply. In this experiment, two air temperature and humidity sensing nodes were connected to the strawberry surface; one soil temperature moisture sensing node was inserted into the medium; one light intensity sensing node was suspended in the greenhouse; one CO2 concentration sensing node was set. Next to the medium. The environmental parameters at 11:00 am from March 5 to March 12 are shown in Table 4. The historical curve of the air temperature in the greenhouse on March 6 is shown in Figure 11, and the historical curve of the air humidity is shown in Figure 12.
Table 4. Indoor environmental parameters.

| Date   | Air temperature (°C) | Air humidity (%RH) | Soil temperature (°C) | Soil water content (%RH) | CO2 Concentration (PPM) | Light intensity (Lux) |
|--------|----------------------|--------------------|-----------------------|-------------------------|-------------------------|-----------------------|
| T1     | T2                   | RH1                | RH2                   | T3                      | H3                      | G                     | LX                   |
| 2018/3/5 | 21.7        | 23.1               | 54.5                  | 52.5                    | 17.7                    | 33.4                  | 409                  | 62475                |
| 2018/3/6 | 24.5        | 23                 | 43.2                  | 46.1                    | 21.5                    | 35.5                  | 408                  | 44615                |
| 2018/3/7 | 19.7        | 17.3               | 72.5                  | 81.7                    | 16.2                    | 36.2                  | 401                  | 12245                |
| 2018/3/8 | 24          | 21.6               | 54.6                  | 57.3                    | 18.8                    | 38.2                  | 413                  | 38510                |
| 2018/3/9 | 20          | 17.1               | 55.4                  | 53.9                    | 19.4                    | 39.7                  | 447                  | 20195                |
| 2018/3/10 | 19.6      | 17.3               | 56.1                  | 55.4                    | 19.2                    | 39.5                  | 462                  | 17510                |
| 2018/3/11 | 22.9       | 21.4               | 53.5                  | 44.3                    | 21.6                    | 36.5                  | 409                  | 18075                |
| 2018/3/12 | 15.1        | 13.4               | 78.7                  | 78.7                    | 16.6                    | 34.3                  | 479                  | 5335                 |

Figure 11. Air temperature curve.

Figure 12. Air humidity curve.
As can be seen from Table 3, Figure 12, and Figure 13, when the illuminance is lowered, the air temperature is lowered, the air humidity is increased, and the CO2 concentration is increased. At this moment, the photosynthesis of crops is weak and the growth is slow. The crops should be light-compensated and the light compensator should start working. Because the external environment is relatively cold, the vent is closed, the fan does not reach the operating conditions, and the laboratory environment environment is simulated. In the simulation experiment, the system can realize the automatic control function when the environmental parameter reaches the warning value. Remote users can observe the growth of crops through video surveillance screens and visually display the growth of crops. The video screen displayed by the remote mobile client is shown in Figure 13.

![Video screen](image)

**Figure 13.** Video screen.

### 6. Conclusions

Through the research on the Internet of Things technology, a greenhouse remote measurement and control system was designed by using WebOP Designer configuration software and Wop-2070T industrial-level human-machine interface. After one month of experimentation, it is summarized as follows:

1) Experiments show that the system implements functions such as collection, display, storage, user access, and control of environmental parameters.

2) The system adopts “WebOP Designer configuration software + WOP-2070T human-machine interface+Adam4117+Adam4060+ relay” to realize node data convergence and actuator control functions, which can realize streamlined data representation and control relay action.

3) The system's network camera can realize the remote observation of crop growth by users, and combined with other environmental parameters such as temperature and humidity, can better judge the growth state of crops.

4) The greenhouse greenhouse has multi-variable, large lag, strong coupling and other characteristics, and the control structure of the system can be further optimized.

5) Through the research on the greenhouse, it was found that the development trend of the control technology of the greenhouse of the facility agriculture is inevitably the fusion of traditional control and intelligent control technologies. While improving crop yields, we will realize the safe traceability of agricultural products throughout the whole process, and steadily and continuously develop in the direction of high yield, high efficiency, environmental protection, energy saving, safety and transparency. As the key development direction of facility agriculture, the remote measurement and control system of greenhouse has broad research and application prospects.
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