Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org

Volume 24, Issues 3, pp. 439–447, DOI 10.12694/scpe.v24i3.2318

REMOTE MONITORING SYSTEM OF DIGITAL AGRICULTURAL GREENHOUSE BASED ON INTERNET OF THINGS

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Abstract. In the actual operation process of the conventional digital agricultural greenhouse monitoring system, there are problems such as limited monitoring scope and large deviation between the monitoring results and the actual situation of the greenhouse. To solve this problem, a new remote monitoring system is proposed by introducing the technology of the Internet of Things. On the basis of the completion of the hardware design of the remote monitoring system, the optimal fusion data value of the remote monitoring of the digital agricultural greenhouse is obtained by establishing the monitoring data fusion model. The particle swarm optimization fuzzy control algorithm is designed to optimize the adaptive remote monitoring process of the system dynamically. The Internet of Things technology is used to deploy the remote monitoring system of digital agricultural greenhouses online to fully ensure the quality and timeliness of the remote monitoring system. The test results show that the new system can significantly improve the greenhouse remote monitoring deviation, and the monitoring value is close to the actual value.

Key words: Internet of Things; System; Digitization; Agricultural greenhouses; Monitor; Long-range

1. Introduction. With the continuous development of greenhouse planting industry, its planting scale is also expanding, and the greenhouse has gradually achieved the goal of digital development. Relying on the Internet of Things and sensor technology, the management level of the greenhouse has been significantly improved [14]. Digital agricultural greenhouse refers to the installation of meteorological stations and soil moisture stations in the greenhouse to monitor the greenhouse air temperature, humidity, carbon dioxide concentration, light, soil pH, soil temperature and moisture, and other factors in real time [6]. According to the monitoring data, the management personnel can master and analyze the environment in the shed, control the opening and closing of heating and lighting, top and side windows, water and fertilizer integration equipment in the hut through a wireless network, and adjust the environment in the shed by controlling the temperature and humidity, so that the crops are always in a suitable growth environment [9]. Digital agricultural greenhouse gas (GHG) monitoring uses digital technologies, such as sensors, IoT devices, and data analytics, to measure, analyze, and manage GHG emissions in agricultural settings, particularly in greenhouse environments.

The advent of digital greenhouses has significantly lowered the labor costs associated with greenhouse farming, boosted the harvests of crops grown in such controlled environments, and increased the economic viability of greenhouse agriculture [16]. In the operation process of the digital greenhouse, a scientific remote monitoring system is needed to grasp the dynamic change information of each area in the greenhouse in real-time and adjust the temperature, humidity, light intensity, and soil pH [15] in the greenhouse in time. At present, the traditional greenhouse remote monitoring system in the actual application process is still not perfect; the monitoring range is limited, affected by interference factors, the monitoring results and the actual situation in the greenhouse have a significant deviation, and can not obtain more accurate monitoring data, and the monitoring time efficiency is poor [5]. As related disciplines constantly advance, the technology behind the Internet of Things has made significant strides forward. It has a large amount of information to obtain the overall processing capacity. Collaborative computer technology has pushed China's agriculture into a more important technological era [8]. With the Internet of Things, we can obtain a certain parameter of the digital agricultural greenhouse, send it through the sensor, conduct a comprehensive analysis of these data, and design various responses to these data to ensure that the operation of the agricultural greenhouse is controlled in a scientific way [10]. It is precisely because of the advanced management of intelligent agriculture that a large

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number of labor forces have been liberated, a large number of materials have been saved, and at the same time, crops have been ensured in the best production environment. Based on this, this paper introduces the Internet of Things technology and proposes a new remote monitoring system for digital agricultural greenhouses.

In general, sensors and IoT (Internet of Things) technologies can be used to monitor the emission of greenhouse gases (GHGs). Several types of sensors are commonly employed for this purpose, including:

1. Gas Sensors: These sensors are designed to detect specific gases, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). They can measure the concentration levels of these gases in the atmosphere, providing valuable data for GHG monitoring.
2. Optical Sensors: Optical sensors utilize light absorption or scattering properties to measure GHG concentrations. For example, infrared (IR) sensors can detect and quantify the levels of GHGs based on their unique absorption patterns in specific wavelengths.
3. Air Quality Sensors: These sensors can monitor multiple environmental parameters, including temperature, humidity, and particulate matter. They can indirectly provide insights into GHG emissions by analyzing air quality changes associated with combustion or industrial processes.
4. Remote Sensing: Remote sensing techniques involve using satellite-based or aerial sensors to capture and analyze data on GHG emissions. These methods provide a broader spatial coverage and can monitor GHG sources across large areas.

The effects of greenhouse gases in agricultural applications are significant. Increased levels of GHGs in the atmosphere, such as CO2 and CH4, contribute to the greenhouse effect, trapping heat and leading to global warming. This warming trend affects various aspects of agriculture:

1. Crop Productivity: Rising temperatures and altered precipitation patterns can impact crop growth, yield, and quality. Some crops may suffer from heat stress, reduced water availability, or increased susceptibility to pests and diseases.
2. Water Resources: Changes in temperature and precipitation patterns can affect water availability for irrigation and crop growth. Droughts, floods, and altered hydrological cycles can disrupt agricultural practices and water management.
3. Soil Health: Increased temperatures and changes in precipitation can impact soil moisture levels, nutrient availability, and microbial activity. These changes can affect soil fertility, nutrient cycling, and overall soil health, influencing crop productivity.
4. Pest and Disease Dynamics: Climate change can alter the geographical distribution and abundance of pests and diseases. Warmer temperatures can extend the growing season for certain pests, leading to increased pest pressure and the need for additional pest management strategies.
5. Livestock Production: Heat stress due to higher temperatures affects livestock health and productivity. Extreme weather events can also disrupt animal husbandry practices and feed availability.

Understanding the effects of GHGs in agricultural applications is crucial for sustainable farming practices, resource management, and adaptation strategies. By monitoring GHG emissions and implementing mitigation measures, the farm sector can work towards reducing its carbon footprint and promoting climate-resilient practices.

2. Hardware design of digital agricultural greenhouse remote monitoring system. In the remote monitoring system of the digital agricultural greenhouse, the data gateway is the transmission bridge of primary environmental data in the greenhouse, which is mainly composed of a microprocessor module, WiFi communication module, 485 serial communication module, and power module. The hardware structure of the remote monitoring system data gateway designed in this paper is shown in Figure 2.1.

As shown in Figure 2.1, the data gateway hardware of the digital agricultural greenhouse remote monitoring system designed in this paper takes the CPU as the core part to coordinate the processing of sensor equipment data. The 485 serial communication module is responsible for uploading the field data of the agricultural greenhouse to the microprocessor and sending the relevant control instructions [2] to the controller. The WiFi module acts as an intermediary between the gateway and cloud server, facilitating the transmission of processed data to the cloud server, receiving control instructions from the same server, and performing decoding analysis [19]. Secondly, the system microprocessor is selected and designed. According to the field investigation of the digital agricultural greenhouse, and after careful consideration of the cost, data processing

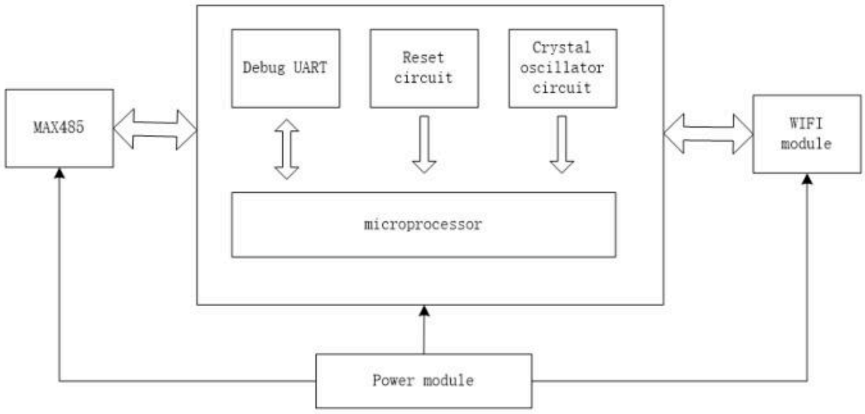

Fig. 2.1: Hardware Structure of Remote Monitoring System Data Gateway

Table 2.1: System Microprocessor Performance Parameter Settings

No	Internal structure	Functional characteristics
1	Kernel	The 32-bit Cortex M3 microcontroller core has a maximum operating frequency of 72 MHz.
2	Storage	Up to 512K bytes of flash memory, 64K bytes of SRAM.
3	Clock, reset, and power management	The I/O pin and supply voltage are 2.0-3.6V. 4-16MHz crystal oscillator embedded A 40 kHz RC oscillator and a 32 kHz RTC oscillator.
4	Low power consumption	It has three modes: sleep, shutdown, and standby, with VBAT as RTC and backup storage power supply.
5	I/O port	Up to 112 fast I/O ports, so the ports can image 16 external interrupts.
6	Communication interface	Up to 13 communication interfaces, 2 IC interfaces, 5 USART interfaces, 3 SPI interfaces, CAN interfaces, and USB 2.0 full-speed interfaces.
7	Debug Mode	With SWD and JTAG interfaces, embedded ETM tracking module.
8	A/D conversion	There are three 12-bit AD converters, 0-3.6V conversion range, triple sampling, and function retention.

speed, safety, and reliability of the system function, this paper finally selects the STM32F103 series and uses the STM32F103TRPD8 microprocessor. Set the microprocessor performance parameters, as shown in Table 2.1.

As shown in Table 2.1, the microprocessor performance parameters designed in this paper can stabilize and adjust the operating power frequency of the system through the microprocessor, reduce the interference impact caused by power fluctuations, and improve the reliability of the system circuit [13].

Design of air temperature and humidity sensor for digital agricultural greenhouse. This paper selects the RS-BYH-M air temperature and humidity sensor that Shandong Jianda Renke Company designed. The sensor is integrated with a temperature and humidity measurement structure, and its output signal is RS485. The internal power supply, induction probe, and signal output are all isolated. The probe is waterproof and sealed at the probe position, which has good waterproof and sealing performance and fully meets the requirements of agricultural greenhouse environmental monitoring [11]. Basic parameter settings of air temperature and humidity sensor are shown in Table 2.2.

Table 2.2: Basic Parameters of Air Temperature and Humidity Sensor

No	Internal structure	Parameter
1	DC power supply	12V-24VDC
2	Maximum power consumption	0.4W
3	Output signal	RS485
4	Corresponding time	< 15S (1m/s wind speed)
5	Temperature long-term stability	≤ 0.1 ° C/y
6	Humidity long-term stability	≤ 1%y
7	Temperature measurement range	-40 ℃ -80 ℃
8	Humidity measurement range	0-100%RH
9	Temperature resolution	0.1 ℃
10	Humidity resolution	0.15RH
11	Working environment pressure range	0.9-1.1atm

Table 2.3: Parameter Settings of Soil Environment Sensor

No	Internal structure	Parameter
1	Moisture measurement range	0-100%
2	Moisture accuracy	0-53%: ± 3%;53-100%: ± 5%
3	Temperature measurement range	-40 ℃ -80 ℃
4	Temperature measurement accuracy	± 0.5 ℃
5	Conductivity measurement range	0-10000us/cm
6	Conductivity resolution	10us/cm
7	Port communication	RS485 Modbus

Set the air temperature and humidity sensor according to the basic parameters shown in Table 2.2, so that it can accurately monitor and collect the temperature and humidity of the digital agricultural greenhouse and provide data support for remote monitoring of digital agricultural greenhouse [12].

The light intensity sensor adopts the ZZ-LRS-LIGHT light intensity sensor designed by Shandong Jianda Renke Company. The sensor adopts a high-sensitivity photosensitive probe with stable signal and high precision and uses RS485 communication. It has a wide measurement range, good linearity, good waterproof performance, convenient use, convenient installation, long transmission distance, etc. [21].

The system uses the soil temperature, humidity, and salinity three-in-one sensor RS-MTUL-GTR3 designed by Shandong Jize Company. The sensor is suitable for measuring soil temperature, soil moisture, and pH values in agricultural greenhouses. It has high precision, fast response, and stable output [4]. It is not affected by soil salinity and is suitable for various soils. It can be buried in the ground for a long time, is resistant to long-term electrolysis, has strong corrosion resistance, vacuum sealed, and is entirely waterproof [24]. Use RS485 serial Modbus standard protocol, easy access to the system, and long transmission distance. The soil environment sensor parameter settings are shown in Table 2.3.

Set the parameters of the soil environment sensor according to the parameters in Table 2.3 to ensure the reliability of its operation.

System HD video surveillance camera. The HD surveillance camera uses real-time video to monitor the growth of crops planted in the greenhouse and the dynamic changes in the greenhouse area [3]. Monitor the changes in digital agricultural greenhouses more intuitively. This system selects the PKI85-PIND5A high-definition video surveillance camera produced by Shandong Konka Ning'an Company. The real-time video surveillance function can meet the need for all-weather video surveillance for digital agricultural greenhouses [20].

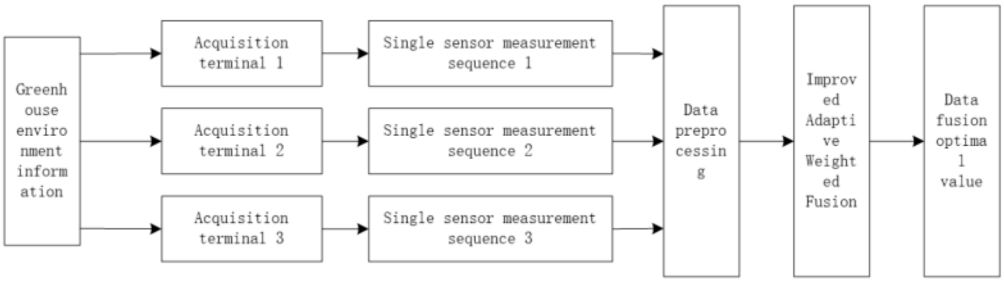

Fig. 3.1: Sensor Data Fusion Model

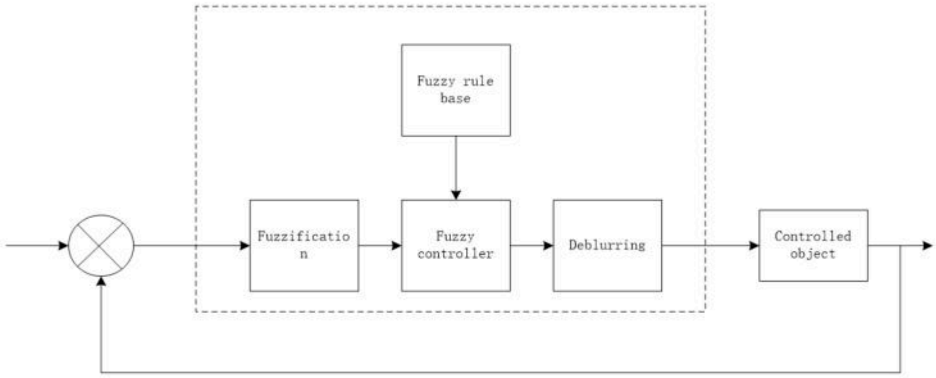

Fig. 3.2: Schematic diagram of the principle of the particle swarm optimization control algorithm

3. Software design of digital agricultural greenhouse remote monitoring system.

3.1. Establish monitoring data fusion model. The environmental data acquisition of a digital agricultural greenhouse depends on each sensor, but there will be a large deviation in the collected value due to the sensor accuracy and collection terminal failure. Based on this, this paper first conducts data preprocessing operations on the collected data of a single sensor and then fuses the collected values of similar sensors through an improved adaptive weighted fusion algorithm. The optimal fusion value [10] is obtained. The sensor data fusion model is shown in Figure 3.1.

As shown in Figure 3.1, through the iterative operation of the model, the outliers with significant measurement deviation are removed, and the optimal fusion data value of digital agricultural greenhouse remote monitoring is obtained to provide data support for subsequent remote monitoring [22].

3.2. Design system particle swarm optimization fuzzy control algorithm. The environment of the remote monitoring system of the digital agricultural greenhouse is complex, many factors need to be considered, and the environmental parameters interact, which makes the design of the monitoring system very challenging. The PID control algorithm and switch control method used in the monitoring system cannot cope with the multivariable and strong coupling characteristics of the greenhouse [7]. Given the limitations mentioned earlier, this paper suggests utilizing the particle swarm optimization algorithm, which can improve optimization speed and requires fewer parameter settings. Furthermore, a fuzzy PID control algorithm will also be employed for dynamic optimization. The principle diagram of the particle swarm optimization control algorithm is shown in Figure 3.2.

As shown in Figure 3.2, the specific process of fuzzy control is to collect the accurate value of the controlled object through the measuring equipment, compare it with the set value of the system, and then write the difference into the fuzzy controller as an input [17]. First, the input value should be fuzzed through the fuzzy interface, and the measured actual value should be converted into a fuzzy vector [1]. Secondly, the fuzzy reasoning steps are carried out. The fuzzy controller operates by executing fuzzy reasoning in accordance with the fuzzy control rules outlined in the knowledge base and makes reasoning decisions on the fuzzy inputs to obtain the corresponding fuzzy output set [18]. The knowledge base consists of two parts: database and rule base. The last step in the control process is to perform the deblurring operation [23]. The blur output can be used to control or drive the actuator through the operation of the deblurring interface. With this in mind, the membership function for the system remote monitoring can be established through the implementation of the particle swarm optimization control algorithm, and the expression is:

$$\mu_e(x) = e^{-\left(\frac{x-m}{\sigma}\right)^2}$$

Among them, $\mu_e(x)$ represents the membership function of the digital agricultural greenhouse remote monitoring system; m, σ they respectively represent the system monitoring image parameters, in which, σ determines the width of the system monitoring function image; m determines the center point of the system monitoring function image. By designing the system particle swarm optimization control algorithm, the adaptive remote monitoring process of the system is dynamically optimized, and the overall operation performance of the system remote monitoring is improved.

The Particle Swarm Optimization Fuzzy Control algorithm (PSO-FC) is a hybrid intelligent control approach that combines Particle Swarm Optimization (PSO) and fuzzy logic to optimize and control complex systems. PSO is a population-based optimization algorithm inspired by the social behavior of bird flocking or fish schooling. Fuzzy logic, on the other hand, is a mathematical framework that deals with uncertainty and imprecise information using linguistic variables and fuzzy rules.

The PSO-FC algorithm involves the following steps:

1. Initialization: Initialize a swarm of particles, each representing a potential solution to the control problem. Each particle has a position and velocity vector.
2. Fitness Evaluation: Evaluate the fitness of each particle based on its current position in the solution space. In the context of fuzzy control, the fitness function assesses the performance of the control system based on predefined criteria or objectives.
3. Update Particle Velocity and Position: Adjust the velocity and position of each particle based on its own experience and the best experience of the swarm. PSO utilizes the concept of social learning, where particles communicate and update their positions based on their own best solution (personal best) and the best solution found by the swarm (global best).
4. Fuzzy Rule Base: Construct a fuzzy rule base that defines the relationships between system inputs, outputs, and control actions. This rule base comprises linguistic variables, fuzzy membership functions, and a set of fuzzy rules.
5. Fuzzy Inference: Apply fuzzy inference using the current system inputs and the fuzzy rule base to determine the appropriate control action or output. Fuzzy inference involves fuzzification (mapping crisp inputs to fuzzy sets), rule matching, aggregation, and defuzzification (mapping fuzzy outputs to crisp values).
6. Control Action Update: Update the control action or output based on the fuzzy inference results.
7. Termination Criterion: Repeat steps 2 to 6 until a termination criterion is met. The termination criterion can be a predefined number of iterations or when the desired control performance is achieved.

The PSO-FC algorithm combines the optimization capabilities of PSO with the reasoning capabilities of fuzzy logic to adaptively adjust control parameters and optimize control performance in complex and uncertain systems. It has been applied in various domains, including robotics, power systems, process control, and intelligent transportation systems, to achieve improved control accuracy, robustness, and adaptability.

3.3. Online deployment based on the Internet of Things. After completing the design of the above particle swarm optimization control algorithm, next, use the Internet of Things technology to deploy the digital agricultural greenhouse remote monitoring system online to fully ensure the quality and timeliness of the system's remote monitoring.

The system's online implementation is divided into three distinct layers - the perception layer, network layer, and application layer, facilitated by the use of Internet of Things technology. The perception layer serves as the primary data collection mechanism, capturing physical events and agricultural greenhouse data while ensuring external information is digitized. The network layer associates environmental data from the perception layer with user data available in the application layer, thereby enhancing the reliability and security of information transmission. Lastly, the application layer processes and computes large volumes of sensory information generated by the digital agricultural greenhouse while enabling seamless interaction with the internet.

Package the back-end project, use FileZilla software, upload the package file to the server-specific folder, install the project dependencies, and use the node Exe. The JS process management tool PM2 starts the project and then uses the "Pm2list" command to view the operation status after the project is started. After the deployment of the back-end project is completed, deploy the front-end project with the same server as above, use the "Npm run build" command to package the project, upload the package file dist to the server through Filezilla, and use NGINX as the reverse proxy to deploy the front-end project.

4. System test.

4.1. Test preparation. In order to verify the effectiveness of the digital agricultural greenhouse remote monitoring system based on the Internet of Things proposed in this paper, the system test is conducted as shown below. First, according to the above system hardware and software design content, build a remote monitoring system. Secondly, establish the required environment for this system test. ZigBee wireless sensor network is constructed with a tree structure, which is composed of a coordinator node, a routing node, and two terminals. The terminal node is responsible for collecting environmental data in the greenhouse and sending it to the router node through the network. The routing node is responsible for gathering the collected data and transmitting it to the coordinator node, which has the responsibility of constructing the entire network and forwarding environmental data to the upper levels of computer architecture through the Internet. The 1852 square meter standard multi-span vegetable greenhouse of a vegetable base was selected for the Zigbee network, greenhouse automatic control, and remote monitoring test. The lower computer and coordinator module were installed in the greenhouse strong current control box or independent weak current control box, and connected to the back-end server through networking.

4.2. Test results. In order to make the system test results more visual and clear, the remote monitoring system of a digital agricultural greenhouse based on the Internet of Things proposed in this paper is set as the experimental group, and the traditional monitoring system is set as the control group. The remote monitoring results of the two systems are compared. Divide the vegetable greenhouse into six monitoring areas with the same shape and size, labeled 01 $\sim$ 06, set temperature and humidity sensors in the divided areas, collect the temperature change data of each area in the greenhouse in real-time, and upload it to the system center. Using MATLAB simulation analysis software, take 24 hours as the monitoring cycle, count the average temperature values of each monitoring area obtained by the two remote monitoring systems, compare the temperature remote monitoring results with the actual temperature values, and determine the accuracy of the system monitoring results. The results are shown in Figure 4.1.

It can be seen from the comparison results in Figure 4.1 that the two digital agricultural greenhouse remote monitoring systems have different operating effects. Among them, after the application of the remote monitoring system of a digital agricultural greenhouse based on the Internet of Things proposed in this paper, it can be seen that the temperature remote monitoring value in the greenhouse is closer to the actual temperature value, and the monitoring deviation is small, which indicates that the remote monitoring result of the proposed method has high accuracy, and the remote monitoring effect has significant advantages.

5. Conclusion. In order to improve the operation function of the traditional agricultural greenhouse remote monitoring system is not perfect, the monitoring results have low accuracy, and there is a large deviation from the actual operation in the greenhouse. The present paper presents the Internet of Things (IoT) technology and proposes a design for a remote monitoring system for digital agricultural greenhouses, that is based on IoT. Through the research in this paper, the goal of remote monitoring of agricultural greenhouses has been well achieved. The remote monitoring results are close to the actual situation in the greenhouses and can obtain

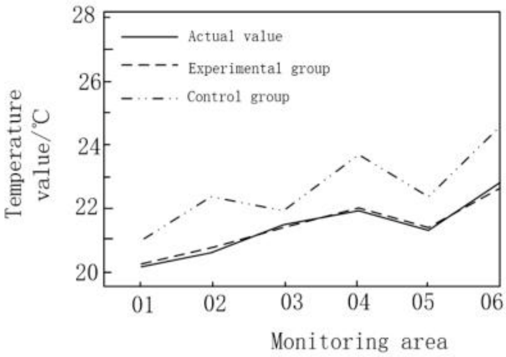

Fig. 4.1: Comparison Results of Remote Monitoring Values of Agricultural Greenhouse Temperature

the monitoring values with high accuracy, so as to grasp the dynamic changes in the agricultural greenhouses in a real-time and remote manner.

Acknowledgments. The 2022 school-level scientific research project of Hainan Vocational University of Science and Technology, Project No. HKKY2022ZD-09

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Edited by: Sathishkumar V E
Special Issue on: Scalability and Sustainability in Distributed Sensor Networks
Received: May 26, 2023
Accepted: Jul 9, 2023