LOW POWER CONSUMPTION MONITORING METHOD OF AGRICULTURAL GREENHOUSE ENVIRONMENT BASED ON WIRELESS SENSOR NETWORK
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基于无线传感器网络的农业温室环境的低功耗监测方法

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ABSTRACT

In order to improve the reliability of wireless sensor networks and reduce the power consumption in the monitoring process, the low power consumption monitoring method of agricultural greenhouse environment based on wireless sensor networks is studied. The terminal node of wireless sensor network is constructed by using CO_2 sensor, temperature and humidity sensor and illumination sensor. In the sensor network layout stage, in order to reduce the node power consumption, considering the number of nodes and network coverage, the cuckoo search algorithm is used to optimize the node layout model. The communication module uses Low Energy Adaptive Clustering Hierarchy (LEACH) protocol to transmit the environmental data collected by the terminal node to the monitoring center. The cluster head link is selected in LEACH protocol to save energy. After receiving the environmental data collected by the terminal node, the monitoring center uses multi-dimensional data to identify and locate abnormal environmental data according to the correlation between multi-modal data streams in the same node, so as to realize the environmental monitoring of agricultural greenhouse. The experimental results show that the data transmission of the research method is stable and reliable, and the node's power consumption in the process of internal environment monitoring of the research object is effectively reduced.

摘要

为了提高无线传感器网络的可靠性并减少监视过程中的功耗，研究了基于无线传感器网络的农业温室环境的低功耗监测方法。无线传感器网络的末端节点是使用CO2传感器，温度和湿度传感器和照明传感器构建的。在传感器网络布局阶段，为了减少节点功耗，考虑到节点和网络覆盖范围，杜鹃搜索算法用于优化节点布局模型。通信模块使用Leach协议将终端节点收集的环境数据传输到监视中心。簇头链接在Leach协议中选择以节省能源。在收到终端节点收集的环境数据之后，监视中心使用多维数据根据同一节点中的多模式数据流之间的相关性来识别和定位异常的环境数据，以实现对农业监测的环境监视温室。实验结果表明，研究方法的数据传输是稳定且可靠的，并且节点在内部环境监测过程中的功耗有效地减少了。

INTRODUCTION

With the rapid development of protected horticulture in China in recent years, by 2015, the total area of agricultural greenhouse in China has exceeded 2.08 million hm^2 (*Pisanu et al. 2020*), of which the cultivated area of protected vegetables in the North has exceeded 1.25 million hm^2. At the same time, with the development of information technology, traditional agriculture is gradually transitioning to fine agriculture (*Li et al., 2021*). Among them, intelligent technologies such as sensors, wireless networks, information processing and decision-making service are gradually applied to the effective management of agricultural greenhouses (*Chan et al., 2019*). Especially in recent years, the development and application of Internet of things communication technology at home and abroad have effectively reduced the complexity (*Honeycutt et al., 2021*) of information transmission in the agricultural greenhouse and promoted the development process of intelligent management of agricultural greenhouse. The normal growth of crops requires appropriate temperature and humidity. Once the environment in the agricultural greenhouse is not well controlled, it is easy to lead to crop yield reduction (*Rosa et al., 2020*), and even disease and death. Therefore, it is of great significance to study an effective and energy-saving environmental monitoring method for agricultural greenhouse.

At present, the monitoring methods of greenhouse include manual control and wired monitoring. The manual control method requires users to have strong perception of the environment. If the control is not appropriate, the time and labor cost will be too high, which will cause huge economic losses.

For the wired monitoring method, *Koroak et al.* designed a low power consumption environmental monitoring and soil moisture measurement system based on Ultra High Frequency Radio Frequency Identification (UHF RFID) (*Koroak et al. 2019*), which used Radio Frequency (RF) technology to monitor the data such as temperature, light, relative humidity and weight moisture content in the soil, providing a simple, cost-effective solution for monitoring and controlling plant growth in modern agriculture. However, the wired monitoring method realizes the regulation of the greenhouse environment by arranging complex wires and related control equipment in the greenhouse, which makes it inconvenient for crops to sow and fertilize, and the wires are often broken in production activities. With the rapid development of Internet of things technology, wireless sensor network technology is applied to greenhouse monitoring, omitting the wiring link, avoiding the problems encountered in traditional greenhouse, and meeting the requirements of real-time monitoring of greenhouse environmental factors. Therefore, Abdulkarem et al. combined wireless sensor network technology with monitoring system (*Abdulkarem et al., 2019*), which improved the defects of manual control method and wired monitoring method, but there was a problem of high node power consumption.

Based on this, the low power consumption monitoring method of agricultural greenhouse environment based on wireless sensor network is researched in this paper. Wireless sensor network is a comprehensive technology integrating multiple disciplines. It can monitor the crop growth, soil, diseases and pests and other information in agricultural greenhouse in real time, facilitate the smooth development of seed collection, irrigation and pest control, and facilitate managers to understand the information in greenhouse in the control room. Through real-time dynamic monitoring, it can promote the level of agricultural management in China to be more intelligent and networked.

MATERIALS AND METHODS

The overall structure of monitoring method

The whole network of low power consumption monitoring methods of agricultural greenhouse environment based on wireless sensor network in the actual monitoring process is composed of monitoring center and ZigBee network. Figure 1 shows the details.

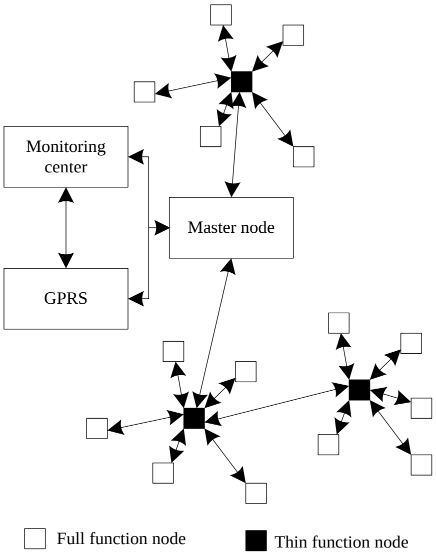


Fig. 1 - Overall structure of low power consumption monitoring method for agricultural greenhouse environment based on wireless sensor network

The overall structure of the low power consumption monitoring method of agricultural greenhouse environment based on wireless sensor network is a hierarchical network structure. The sensor terminal node is at the bottom, followed by ZigBee master node (Coordinator) and monitoring center. The monitoring center is a computer, which is used to display the environmental monitoring data of agricultural greenhouse and send commands to the network. ZigBee network is responsible for collecting environmental data of agricultural greenhouse. It is composed of ZigBee master node and ZigBee terminal node (*Shan et al. 2019*). The terminal node is a sensor star network composed of a full function node and a thin function node.

The full function node collects the environmental data uploaded by the terminal equipment and transmits it to the thin function node. The thin function node integrates and uploads the data and sends the integrated environmental data to the ZigBee master node. There must be a ZigBee coordinator in each wireless sensor network, which is responsible for initiating the network, managing and maintaining it, including assigning network address to newly added devices, joining and leaving nodes, distribution and update of network security key, etc. In order to prevent nodes from joining any network, resulting in uneven power consumption distribution of network nodes, the network is divided into several small star networks, and each star network is defined as a group. The central node of the star network integrates the environmental information of the agricultural greenhouse uploaded by the terminal equipment, and then sends the integrated environmental data of the agricultural greenhouse to the ZigBee master node. There are two ways to connect ZigBee network with the monitoring center. Generally, the coordinator can be directly connected with the monitoring center through serial port. When it is not convenient for the monitoring center to use on site for a long time, GPRS can be used to send the environmental data of agricultural greenhouse to the monitoring center connected with GPRS receiving device.

The monitoring center needs to monitor the working status and health of the sensor node, display the source address of all data, the environmental data of agricultural greenhouse collected by the sensor and the change trend of the data (*Grace and Manju, 2019*), and adjust the work task of the node accordingly. The health status of nodes includes the remaining energy, the working status of sensors and communication components. By monitoring the sensor status, the work cycle of sensor nodes can be adjusted in time and tasks can be reassigned, so as to reduce the application power consumption of wireless sensor networks, avoid premature failure of nodes and prolong the life of the whole network. At present, the residual energy information of nodes is mainly judged by the working voltage of nodes. If the voltage value is too low, the reliability of the node reading sensor data will also be reduced. Therefore, it is necessary to prolong the sleep time of the node with too low voltage and reduce the sampling frequency.

Deployment of terminal node in wireless sensor network

Structure design of terminal node in wireless sensor network

In the process of low power consumption monitoring of agricultural greenhouse environment, the sensor terminal node is at the bottom of wireless sensor network, and its function is mainly completed by the sensor node based on Internet of things data transmission. The sensor node uses ARM Cortex M3 Series MCU (STM32F103R) as the core microprocessor to communicate with the sensor module and wireless communication module. Figure 2 is the structural block diagram of the sensor node. Lithium battery is used for independent power supply, and time-sharing multiplexing of multi-channel sensors is supported for environmental data acquisition of agricultural greenhouse. The backplane provides Flash chip (W25Q64BV) and writes the collected environmental data of agricultural greenhouse as required. The reserved Universal Asynchronous Receiver/Transmitter (UART) communication interface can realize wired reading of node data and avoid the loss of environmental data of agricultural greenhouse caused by insufficient power and poor wireless communication quality. Considering the low transmission power of wireless communication module NRF24L01 and serious plant shielding in the agricultural greenhouse environment, the power adjustable RF amplification chip RFX2401C is used for power amplification to ensure that the wireless transmission can achieve the required transmission power in the agricultural greenhouse environment.

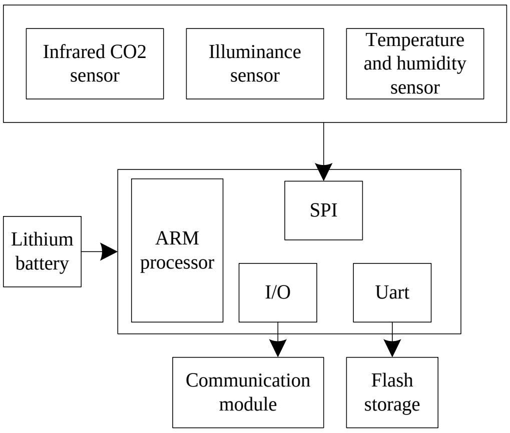


Fig. 2 - Node structure of wireless sensor network

The sensor node comprises a power supply battery, a CO_2 sensor and corresponding circuit parts, which are encapsulated in a waterproof box with the size of (8×8×4.5) cm^3. In order to prevent the high humidity environment in the agricultural greenhouse environment from affecting the internal infrared carbon dioxide sensor and measuring circuit (*Saban et al., 2021*), the waterproof breathable membrane made of EPTFE material is used at the vent hole of the outer wall for waterproof and breathable treatment. The air after waterproof treatment will not affect the measurement of the internal infrared carbon dioxide sensor. At the same time, the condensation phenomenon caused by the large temperature difference between day and night in the agricultural greenhouse environment is avoided. The temperature and humidity sensor, illumination sensor and wireless communication antenna are exposed outside the shell to realize the accurate measurement of environmental factors of agricultural greenhouse and wireless transmission of data.

Considering the semi enclosed environment of agricultural greenhouse, the minimum volume fraction of CO_2 in daytime can reach 2×10^{-4} below, and accurate CO_2 concentration measurement directly affects the decision-making gas fertilizer irrigation of greenhouse agriculture. The traditional electrochemical sensor (such as MG811) has a high detection lower limit (4×10^{-4}) and large power consumption (1.2W), which cannot meet the lower limit of measurement of closed agricultural greenhouse and cannot work independently for a long time, so they are not suitable for the design requirements of sensor nodes in wireless sensor networks. At the same time, due to the complex application environment of agricultural greenhouse, the injected methane and other gas components released by chemical fertilizer and soil greatly limit the availability of semiconductor CO_2 sensors (*Haque et al., 2020*). On the premise of considering the cost performance, S300 infrared CO_2 sensor designed based on direct absorption method is selected as the sensor node to measure the CO_2 concentration in agricultural greenhouse. Compared with electrochemical and semiconductor sensors, it ensures higher measurement accuracy and lower detection limit.

According to the variation range of environmental temperature and humidity of agricultural greenhouse and the demand of low-cost miniaturization design, SHT15 temperature and humidity sensor is selected as the sensor node to measure the temperature and humidity in the greenhouse, and the corresponding nonlinear correction is carried out to improve its detection accuracy. BH1750FVI digital illuminance sensor is used to measure the illuminance. The measurement center wavelength is 560 nm, which is in the visible range. The measurement results have high resolution, and the measurement range is 1～65 535 lx.

Node deployment model

In the deployment of wireless sensor nodes, increasing the number of sensors is usually used to improve the network coverage in the agricultural greenhouse environment. However, deploying too many sensors will produce a large number of redundant nodes, resulting in data transmission conflicts, waste of resources and the instability of the network. Therefore, in order to achieve the purpose of low power consumption monitoring, the number of nodes and network coverage are considered at the same time in the layout stage of sensor networks.

The coordinate system is established with the center point of the greenhouse area as the origin, and the east direction as the positive direction of the x-axis of the coordinate axis. Because the greenhouse is usually built in a flat area, excessive gradient difference in the greenhouse will affect the uniformity of the temperature in the greenhouse, so the influence of height factor is not considered, and only the plane is assumed. Assuming that each sensor in the wireless sensor network has the same communication radius and sensing radius (*Rienzo et al., 2020*), let $w=\{w_1,w_2,w_3,\cdots w_n\}$ be a set of wireless sensors, (x_i,y_i) be the coordinate of any wireless sensor node w_i in the set, and (x_j,y_j) be the coordinate of any point w_j in the environmental monitoring area of agricultural greenhouse, then the Euclidean distance from node w_i to point w_j is defined as *(Mabrouki J et al., 2019)*:

$$d\left(w_i,w_j\right)=\sqrt{\left(x_j-x_i\right)^2+\left(y_j-y_i\right)^2} \tag{1}$$

The environmental monitoring area a of agricultural greenhouse is discretized into a grid point, point K with coordinate (x,y), to judge whether point K is covered by sensor node w_i, which can be expressed by equation (2):

$$P\left(K,w_i\right)=\begin{cases}1,d\left(w_i,p_j\right)\le r\\0,\text{otherwise}\end{cases}\tag{2}$$

In formula (2), r represents the radius of the detection area. For any coordinate point $\left(x,y\right)$, as long as there is a sensor node in node B so that $F_{\text{cov}}\left(x,y,b_i\right)=1$, b_i represents the total number of sensor nodes in the current area, it means that the point is covered by at least one sensor node, and the joint measurement coverage $F_{\text{cov}}\left(B\right)$ of the node set is:

$$F_{\text{cov}}\left(B\right)=\left(1-\prod_{b_i\in B}\left(1-F_{\text{cov}}\left(x,y,b_i\right)\right)\right)\times\phi\tag{3}$$

Where ϕ represents the coverage correction value, the coverage correction value is generally 0.75.

After simplifying small grid points into grid points, the coverage of wireless sensor network is defined as the proportion of the number of discovered grids to the total number of grids (*Fakhri et al., 2020*), that is:

$$F_a=\sum_{x=1}^{m}\sum_{y=1}^{n}F_{\text{cov}}\left(B\right)\times\frac{1}{m\times n}\tag{4}$$

In order to use the optimization algorithm to solve the problem of optimal deployment of wireless sensor networks for environmental monitoring of agricultural greenhouse, the network coverage objective function and constraints are defined as follows:

$$\begin{cases}\overline{F}=m\times n\times\dfrac{1}{\sum_{x=1}^{m}\sum_{y=1}^{n}F_{\text{cov}}\left(B\right)}\\m\le h_m\\n\le h_n\\F_{\text{cov}}\left(B\right)\ge 1\end{cases}\tag{5}$$

The cuckoo search algorithm is used to solve the objective function. The goal of the research is to maximize the function. It is expected to obtain wider coverage, so as to improve the monitoring capability of the network. After deploying the wireless sensor network node, the communication protocol is used to realize the transmission of agricultural greenhouse environmental monitoring data between the wireless sensor network node and the monitoring center.

Communication protocol

The improved LEACH communication protocol is adopted in the process of environmental monitoring of agricultural greenhouse. The traditional LEACH protocol randomly divides the area distributed by the sensors into pieces. In each piece, a node with sufficient energy is randomly selected as the cluster head node through the algorithm to communicate with the outside world.

The operation of LEACH protocol is divided into two rounds, and each round is divided into two parts: establishment stage and stability stage *(Rezvani et al., 2020*). The establishment stage is self-organized into clusters. In each round, the nodes become the cluster head node with the probability of $G_i\left(t\right)$. After becoming the cluster head node, they broadcast messages, and the node receiving the information sends a join request to the cluster head node, and the cluster sends back the confirmation information; In the stable stage, the cluster head node collects the information sent from the members in the cluster, and then sends it to the sink node after processing, which circulates in turn. $G_i\left(t\right)$ is calculated as follows:

$$G_i\left(t\right)=\begin{cases}k\times\dfrac{1}{N-k^*\left(o\,\text{mod}(\dfrac{N}{k})\right)},H_i\left(t\right)=1\\0,H_i\left(t\right)=0\end{cases}\tag{6}$$

In equation (6), k is the expected value of the node becoming the cluster head node, t is time, mod is residual function, o is the current number of rounds, N is the number of nodes in the network, and $H_i(t)$ is the prediction function (*Ge X et al., 2019*).

In the process of environmental monitoring of agricultural greenhouse, LEACH protocol does not need to randomly select cluster heads, but only needs the reliability of data transmission and the robustness of communication network. Therefore, the protocol needs to be improved to adapt to the specific application of environmental monitoring of agricultural greenhouse. LEACH protocol selects cluster heads through G probability (*Khan et al. 2021*), which will consume part of the energy of nodes. In the improved protocol, there is no need to poll to select cluster heads. Therefore, after selecting cluster heads for the first time, it is no longer necessary to run the algorithm, so as to save energy.

According to the energy dissipation model of LEACH protocol, the energy attenuation of sending data and receiving data in wireless sensor networks are as follows:

$$\begin{cases} S_{Tx} = S_{Tx-elec}(l)S_{Tx-amp}(l,d) \\ S_{Rx}(l) = S_{Rx-elec}(l) = lS_{elec} \end{cases} \tag{7}$$

where, S_{elec} represents the energy consumption of transceiver circuit of wireless sensor network, d represents the distance between nodes, and l represents the number of data bits to be launched or accepted. S_{Tx} represents the energy attenuation of the data sent by the sensor network, S_{Rx} represents the energy attenuation of the data received by the sensor network, $S_{Tx-elec}$ represents the energy consumption of the sending circuit, $S_{Rx-elec}$ represents the energy consumption of the receiving circuit, and S_{Tx-amp} represents the energy consumption of the sending current.

According to the design requirements of wireless sensor network for monitoring the environment of agricultural greenhouse, the protocol assumes that each agricultural greenhouse has n_i ($i=1,2,3,\cdots,k$) nodes, and $g(0\le g\le 1)$ is the success prediction probability of the base station, that is, at this time, the node needs to send prediction data to the greenhouse cluster head. According to the judgment of the cluster head, if it is the probability of g, it will not send, and if it is the probability of $(1-g)$, it will send fusion data.

According to the description, the energy consumption of cluster head nodes in a single agricultural greenhouse cluster is:

$$S_{CH} = lS_{elec}(n_i-1) + lS_{DA}n_i + lS_{elec} + l(1-p)d_{toBS}^4 \tag{8}$$

where, S_{DA} represents the energy consumption of environmental detection data fusion in agricultural greenhouse, and d_{toBS}^4 represents the distance from the node to the base station.

The energy consumption of non-cluster head nodes in each round is:

$$S_{non-CH} = lS_{elec} + ld_{toCH}^2 \tag{9}$$

Where, d_{toCH}^2 is the distance from the node to the cluster head.

The energy consumption of an agricultural greenhouse cluster in each round is:

$$S_C = S_{CH} + (n_i-1)S_{non-CH} \tag{10}$$

Then the energy consumption of wireless sensor network nodes in the whole greenhouse base in one round is:

$$S_{to} = \sum_{i=1}^{s}\left[n_i\left(2S_{elec} + S_{DA} + d_{tpCH}^2 + (1-g)\right)d_{tpBS}^4\right] \tag{11}$$

Identification and location of abnormal data in wireless sensor networks

Abnormal data identification

In the process of environmental detection of agricultural greenhouse, the measured value of wireless sensor network should accurately reproduce the actual environmental characteristics of agricultural greenhouse. Therefore, the measured value $c_j(t_i)$ shows slow fluctuation within a certain range in a stable agricultural greenhouse environment (*Picallo et al. 2021*), but there will be obvious deviation in a short time in case of abnormality. If $c_j\left(t_i\right)$ satisfies equation (12), the measured value may be abnormal data:

$$\left|c_j\left(t_i\right)-\frac{Q_{ej}\left(t\right)+Q_{nj}\left(t\right)}{2}\right|>\gamma^2 \tag{12}$$

where: t is the corresponding sampling time of the wireless sensor network node; $Q_{ej}\left(t\right)$ represents the mathematical expectation of the measured value of the sensor in the agricultural greenhouse environmental monitoring area, $Q_{nj}\left(t\right)$ represents the mathematical expectation of the measured value in the agricultural greenhouse monitoring area under general conditions, which is derived from the measured data in the same period over the years; It is generally believed that $Q_{nj}\left(t\right)$ is a constant in a stable environment. The values of $Q_{ej}\left(t\right)$ and $Q_{nj}\left(t\right)$ in different environments are different, which should be determined according to the environmental monitoring data set of agricultural greenhouses, and γ represents the variance of sampling data.

In addition, when the wireless sensor itself fails (energy is exhausted or damaged and cannot work normally), it may continuously produce the same readings at different sampling times (Bai et al. 2019), that is:

$$c_j\left(t_i\right)=c_j\left(t_{i-1}\right) \tag{13}$$

The above two cases are called the judgment conditions to judge whether the sensor reading is abnormal, and on this basis, the abnormal probability $P_j\left(t_i\right)$ of single-mode data flow is calculated:

$$P_j\left(t_i\right)=P_j\left(t_{i-1}\right)+r\cdot u^2 \tag{14}$$

The single-mode anomaly probability $P_j\left(t_i\right)$ is an accumulated value. The probability of anomaly at sampling time t_i is expressed in $P_j\left(t_i\right)$, the probability of anomaly at previous sampling time t_{i-1} is expressed in $P_j\left(t_{i-1}\right)$, the number of times meets the judgment conditions is expressed in constant u, and r represents the radius of the detection area. If the reading $c_j\left(t_i\right)$ continuously meets the judgment conditions at several sampling times, u increases gradually from 0. At this time, $P_j\left(t_i\right)$ and u have an exponential relationship. If $c_j\left(t_i\right)$ does not meet the judgment conditions, u, $P_j\left(t_{i-1}\right)$ and $P_j\left(t_i\right)$ are cleared at the same time. When $c_j\left(t_i\right)$ meets the judgment conditions, the accumulation starts again.

In the process of environmental monitoring of agricultural greenhouse, a variety of sensors can be integrated in the wireless sensor network to collect multimodal data streams at a certain sampling time and generate multiple groups of $P_j\left(t_i\right)$ values. However, it is not accurate to judge the cause of data anomaly only through a single-mode data flow, and it needs to fuse multi-mode data flow for analysis and judgment. The multi-mode anomaly probability $P_T\left(t_i\right)$ can be calculated from multiple groups of single-mode anomaly probability $P_j\left(t_i\right)$ values:

$$P_T\left(t_i\right)=\sum_{j=1}^{m}\varsigma_j\cdot P_j\left(t_i\right),\left(\sum_{j=1}^{m}\partial_j=1\right) \tag{15}$$

Where, the weight coefficient is expressed by ς_j. Considering that there may be differences in $P_j\left(t_i\right)$ values of different data, some are larger and some are relatively smaller, in order to balance the impact of different $P_j\left(t_i\right)$ on $P_T\left(t_i\right)$, ς_j of data with fast fluctuation frequency and large amplitude is set to a larger value to improve the sensitivity of the algorithm; On the contrary, ς_j is set to a smaller value to effectively avoid misjudgment due to individual data. Considering that ς_j is related to the fluctuation range of the data, its value can be consistent with the standard deviation ratio of the data in proportion (*Rosero-Montalvo et al., 2020*).

Abnormal source location

When the $P_T(t_i)$ value of a sensor node in the wireless sensor network reaches the threshold $C_{th} = \sum_{j=1}^{m} \partial_j \cdot \frac{Q_{ej}(t)+Q_{nj}(t)}{2}$, it is considered that the agricultural greenhouse environment of the node may be abnormal. Considering the differences of multimodal data sets and the robustness of methods, it is inappropriate to set C_{th} as a fixed value, and the value of C_{th} should be related to the statistical characteristics of the data set and highlight different influence factors. Therefore, C_{th} is set as the weighted average of the mean value of the cube, which not only reflects its correlation with all data sets, but also ensures that there are differences between different data sets; In order to confirm the source of the anomaly, spatial correlation needs to be used for verification. When a node detects its own suspected abnormality, it sends a request message to its adjacent node through the wireless channel and receives the $P_T(t_i)$ value of the adjacent node. According to the Laida Criterion (*Zhou et al., 2020*), if the $P_T(t_i)$ value of the node meets $\left|P_T(t_i)-\psi\right| < \gamma\varepsilon$ (ψ and ε are the mean and standard deviation of $P_T(t_i)$ value of the neighbor node respectively), it is considered that the error comes from the random error in the process of the event, and the state of this node is consistent with that of the neighbor node; If not, it is considered that the state of this node is inconsistent with that of the adjacent node, and there is a fault or measurement error. γ needs to be taken according to the specific situation, but generally, the event process can be regarded as a Bernoulli process in which the random variable conforms to the normal distribution, so the random variable can be simplified into a random variable with standard normal distribution:

$$p = P\left(\frac{\left|P_T(t_i)-\psi\right|}{\varepsilon} \geq \gamma\right) = 2-2\Phi(\gamma) \tag{16}$$

Where: $\Phi(\gamma)$ represents the standard normal distribution. By looking up the table, we can find that when $\Phi(\gamma) > 0.975$, $p < 0.05$; when γ is about greater than 1.96, $\Phi(\gamma) > 0.975$, it can take $\gamma = 2$. The specific judgment conditions of abnormal source are as follows:

If $c_j(t_i) \neq c_j(t_{i-1})$ and $\left|P_T(t_i)-\psi\right| < 2\varepsilon$, it is considered that significant environmental changes have occurred in the agricultural greenhouse;

If $c_j(t_i) = c_j(t_{i-1})$ and $\left|P_T(t_i)-\psi\right| \geq 2\varepsilon$, the sensor is considered to have failed;

If the above conditions are not met, it is considered that there may be measurement errors. It is necessary to further detect the possible measurement errors and screen out the data with measurement errors.

RESULTS

In order to verify the application effect of the low power consumption environmental monitoring method for agricultural greenhouse based on wireless sensor network in the actual environmental monitoring process, a large strawberry greenhouse is selected as the research object. During the test, the plant is in the mature stage. The solar greenhouse is a column less arched roof greenhouse with an area of 250×8 m^2, with a height of about 3 m. The canopy is covered with straw curtain at night to achieve the effect of thermal insulation at night. The method in this paper is used to monitor the internal environment of the research object. In the process of monitoring, in order to avoid the generation of antenna gain, the same antenna is used at the transmitting end and the receiving end. The antenna direction of the transmitting and receiving node is the same, and the height from the ground is greater than 0.5 m. The monitoring sensor device is shown in Figure 3.

Considering the indoor environmental area of the shed and the monitoring range of the sensor, 83 sensors are placed in the whole shed with the first sensor coordinate (0,0) as the origin, and each sensor device is 6 meters apart. The host computer software monitors and records the wireless signal strength (RSSI) in real time.

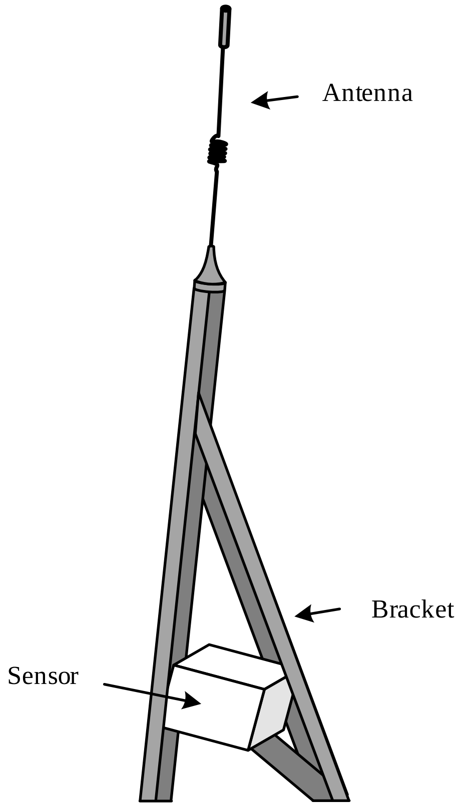


Fig. 3 - Monitoring sensor device

The experimental time is October 2021, and the sampling data are all taken from the sampling results on the first day. The experimental parameter settings are shown in Table 1.

Table 1

Experimental Parameter Setting

Parameter	Numerical value
m	250
n	8
d	6
ϕ	0.75
Sensitivity	2mV/V
Temperature resolution	0.01°C
Carbon dioxide concentration resolution	0.01ppm
Illumination resolution	0.1lx

Actual monitoring results

Using the method in this paper to monitor the internal environmental information of the research object, the data can be easily presented through the monitoring interface of the monitoring center. Taking carbon dioxide concentration, temperature and illumination as examples to test whether this method can work normally and whether the performance of this method can meet the needs of environmental monitoring of the research object. The test is on one day. The carbon dioxide concentration, temperature and illuminance information in the experimental object are monitored every 1 hour, and the deviation results are obtained by comparing with the actual environmental information.

The comparison of the measured data is shown in Table 2.

Table 2

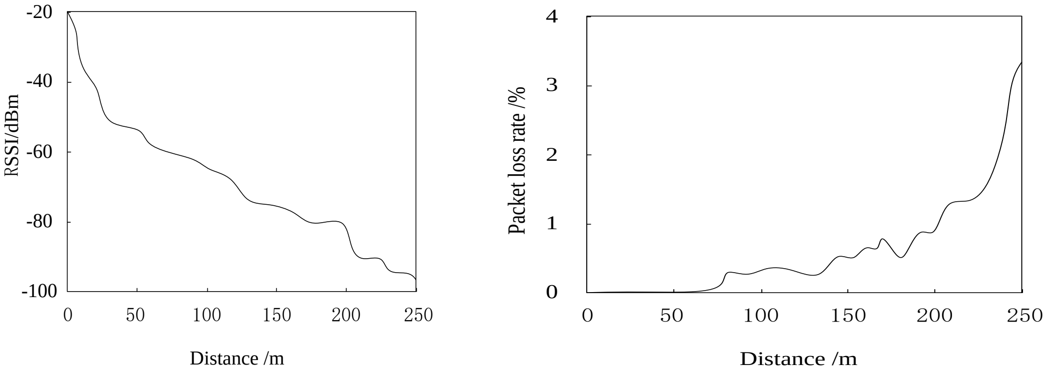
- Monitoring results of internal environmental information of the research object

Time	Carbon dioxide concentration		Temperature		Illuminance	
	Monitoring value / ppm	Deviation/ %	Monitoring value / ℃	Deviation/ %	Monitoring value/ lx	Deviation / %
0:00	359	0.16	12.2	0.11	897	0.02
1:00	362	0.15	11.8	0.09	898	0.01
2:00	360	0.17	11.9	0.04	897	0.03
3:00	359	0.07	11.9	0.02	898	0.00
4:00	361	0.09	12.1	0.07	898	0.01
5:00	357	0.12	12.7	0.05	902	0.05
6:00	301	0.16	14.3	0.10	924	0.05
7:00	225	0.18	15.6	0.12	938	0.08
8:00	199	0.22	18.0	0.04	957	0.06
9:00	192	0.15	19.8	0.07	962	0.07
10:00	194	0.24	21.5	0.02	967	0.09
11:00	182	0.26	23.6	0.09	981	0.04
12:00	179	0.20	23.9	0.04	984	0.02
13:00	181	0.14	23.8	0.05	982	0.00
14:00	183	0.18	23.6	0.08	975	0.01
15:00	196	0.21	22.4	0.03	966	0.05
16:00	205	0.17	20.7	0.14	920	0.03
17:00	229	0.15	18.0	0.08	903	0.04
18:00	268	0.13	16.1	0.05	900	0.02
19:00	327	0.22	15.7	0.00	898	0.00
20:00	346	0.20	15.3	0.02	897	0.01
21:00	358	0.16	14.4	0.07	897	0.00
22:00	359	0.14	13.2	0.02	897	0.00
23:00	359	0.11	12.3	0.05	897	0.01

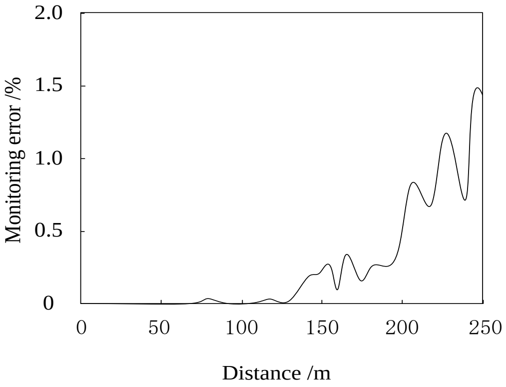
By analyzing the monitoring data in Table 2, it can be obtained that there is a certain error among the carbon dioxide concentration, temperature, illumination and other data obtained by using the method in this paper to monitor the internal environment of the research object and the actual environmental data, but the error is relatively small. Among them, the carbon dioxide concentration error is the largest, which is basically controlled between 0.10% and 0.25%; the temperature error shall be controlled between 0.00% and 0.15%; the illuminance error is the smallest, which is basically controlled below 0.10%. The above error values are within the allowable range, which shows that this method can effectively achieve the purpose of internal environmental monitoring of the research object. At the same time, the monitoring data obtained in Table 1 are transmitted through ZigBee wireless sensor network, which also shows that the data transmission of wireless sensor network used in this method is stable and reliable.

Performance test of wireless sensor network

The construction and application performance of wireless sensor networks are the key to the performance of the method in this paper. Therefore, the changes of wireless signal strength, packet loss rate and monitoring error of the wireless sensor network built in this method under different wireless communication distances are analyzed. The results are shown in Figure 4.



(a) Wireless signal strength (b) Packet loss rate



(c) Monitoring error

Fig. 4 - Performance test results of wireless communication

Figure 4 (a) shows the change trend of the received wireless signal strength value with the increase of transmission distance. Through analysis, it can be seen that the wireless signal strength value gradually decreases with the increase of wireless communication distance. When the transmission distance is within 0-25 m, the wireless signal strength value changes obviously, rapidly reducing from – 20 dBm to about – 50 dBm. With the further increase of wireless communication distance, the wireless signal strength shows a relatively slow change trend. When the wireless communication distance reaches 200 m, the wireless signal strength decreases to about - 80 dBm. When the wireless communication distance is higher than 200 m and reaches 250 m, the decline range of wireless signal strength increases to about – 95 dBm. The test results accord with the theoretical relationship that the wireless signal strength changes with the increase of wireless communication distance.

Figure 4 (b) shows the relationship between the packet loss rate of internal environment monitoring data transmission of the research object and the increase of wireless communication distance. The analysis shows that when the wireless communication distance is less than 75 m, the packet loss rate of environmental monitoring data transmission is basically controlled at about 0%; as the wireless communication distance increases, the packet loss rate of environmental monitoring data transmission tends to increase gradually. When the wireless communication distance reaches 200 m, that is, when the wireless signal strength value is lower than -80 dBm, the packet loss rate of environmental monitoring data transmission is always controlled within 1%, and the rate of increase is relatively gentle; When the wireless communication distance is higher than 200 m, the increase in the packet loss rate of environmental monitoring data transmission fluctuates significantly, from 1% to about 3.3%. The data retransmission caused by the increase of the packet loss rate means that the power consumption of the sensor node energy is further increased, and the service life is shortened.

Figure 4 (c) shows the variation relationship of environmental information monitoring error with the increase of wireless communication distance. Through analysis, it can be seen that when the wireless communication distance is within 125 m, the fluctuation of monitoring error is relatively stable, basically controlled at about 0%, and the monitoring accuracy is high; When the wireless communication distance is between 125 and 200 m, the monitoring error will fluctuate slightly, which is basically controlled within 0.5%;

When the wireless communication distance is higher than 200 m, the monitoring error is accompanied by large fluctuation.

Based on the above analysis, it can be concluded that using the method in this paper to monitor the internal environmental information of the research object has better information transmission performance.

Comparison of power consumption

The power consumed by the internal environmental monitoring of the research object before and after using the method in this paper is compared. The results are shown in Figure 5.

By analyzing Figure 5, it can be seen that before adopting the method in this paper, the average power consumption of nodes in the process of monitoring the internal environment of the research object is about 64 W; After using the method in this paper, the node power consumption of the internal environment monitoring of the research object is about 37 W, which is 36% lower than before. This shows that using this method can effectively reduce the node power consumption in the process of internal environment monitoring. This is because in the deployment stage of sensor nodes, the number of nodes and network coverage are considered at the same time to prevent data transmission conflict and resource waste. At the same time, LEACH protocol is optimized in the process of node communication so that it does not need to randomly select cluster heads, so as to save energy.

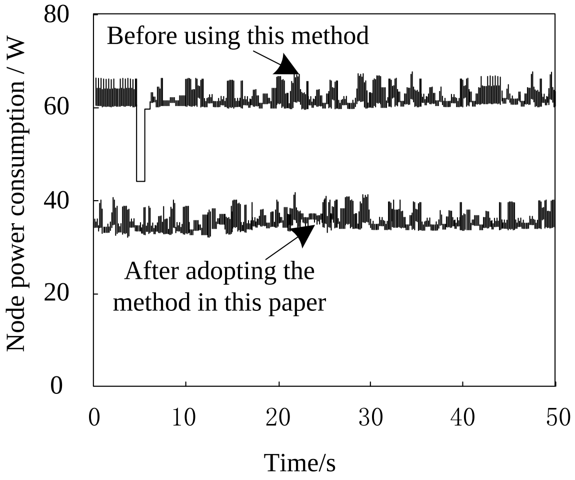


Fig. 5 - Comparison results of power consumption

CONCLUSIONS

According to the needs of environmental monitoring of modern agricultural greenhouse, the low power consumption monitoring method of agricultural greenhouse environment based on wireless sensor network is studied. This method can efficiently monitor the environmental parameters of agricultural greenhouse, including temperature, humidity and light intensity, and has the characteristics of low power consumption, high reliability and stable power supply. Because the research focus of this method is to improve the reliability of wireless sensor networks and reduce the power consumption in the monitoring process, we should further improve the routing protocol and improve the real-time and stability of wireless sensor networks in the future.

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