International Journal of Computational Intelligence Systems and Applications. Volume 6, Issue 1, (2018) 1-12
http://www.cayley-nielson.com/ijcisa/

The Monitoring System about Tomato Growth Based on Wireless Sensor Network

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Abstract

Nowadays, most parts of China are many disadvantages such as less land, poor soil quality, lack of soil resources and changeable climatic conditions. Due to the fact that high-technology is not widely used in agricultural production. To this end, a multi-sensor based on the greenhouse plant growth monitoring system design is proposed. Demand for plant growth, ZigBee wireless sensor network technology is selected to design the hardware structure, make appropriate monitoring parameters and select on-demand networking mode to form a greenhouse plant growth monitoring system. Taking the growth status of tomato in the greenhouse as an example, the pelvic floor is selected as the monitoring site to measure the antenna output power (W) and the maximum effective communication distance (S), the antenna output power (W) and the node operating current (I). The experimental results show that the antenna output power (W) and the maximum effective communication distance (S) of the monitoring system of greenhouse plant growth have a quadratic function increasing relationship. The relationship of the antenna output power (W) and node operating current (I) is linear, with a linearity R of 0.93. It lays a theoretical foundation for the development of modern agriculture and ecological agriculture.

Keywords: Wireless Sensor Network, Greenhouse, ZigBee, Environmental Detection.

1. Introduction

With the continuous increase of our population, food is the foundation for the growth and development of the country. According to the 2013 national land survey, the total cultivated area is 20.3 billion mu, ranking the fourth in the world. However, the per capita arable land area is only 1.4 mu, only ranking the one hundred and twenty-six. The problem of grain supply is becoming more and more serious[1].

In recent years, the rapid development of China's facility agriculture has resulted in more than 4 million hectares in the country[2]. Among them, the modern greenhouse occupies a large proportion. Greenhouse agriculture produces anti-season crops to seize the market and raise farmers' incomes[3]. According to statistics, at present, China needs to spend 50% of operating costs on greenhouse environmental monitoring[4], resulting in excessive operating costs of modern greenhouses and seriously affecting the actual use of modern greenhouses[5-6]. Therefore, establishing a monitoring system of agricultural environmental parameters which is easy to use and cost less is the most important task in developing greenhouse agriculture[7].

With the rapid development of microelectronic technology, information acquisition and processing technology, network and wireless communication technology through the sensor node information acquisition, processing and analysis, to achieve the desired results, has been the growing concern and attention[8]. The Europe, represented by the Netherlands, have started to apply the wireless sensor network technology to greenhouse cultivation[9]. The greenhouse system has started to develop in a networked and wireless manner[10]. At present, the traditional greenhouse environmental monitoring system using wired communication technology in our country requires a large number of cables and power supplies for the construction of the entire system. Due to the complexity of environmental factors in the greenhouse, cables and power sources may corrode and deteriorate, so the research on the greenhouse environmental monitoring system needs to be depended[11-12].

In order to explore the application of wireless sensor network technology in greenhouse agriculture, this paper presents a design of greenhouse vegetation monitoring system based on wireless multi-sensor fusion. Taking the growth status of tomatoes as an example, this paper studies the sensor nodes' data collection for greenhouse environment, the transmission of data by wireless networks, the processing and storage of monitoring data by the host computer, and prepares for more intelligent new agriculture in the future.

2. Working Principle

2.1. Map Loaded

Wireless sensor network is a special self-organizing network. A large number of sensor nodes and data collection nodes are located in specific locations. These nodes are small, inexpensive and have extremely low power consumption with wireless communications, parameter monitoring and data processing capabilities[13-15]. At the same time, these nodes can be self-organized into a network to collect and save a variety of parameters in the monitoring area and transmit them to the host computer for integration so as to realize the expected functions. Therefore, these nodes are widely used in many occasions[16].

2.2. Zigbee Technical Characteristics

ZigBee technology in order to avoid data conflict in the sending process, set up a special time gap, through the time gap to distinguish data transmission. At the same time between the sender and receiver using a response to the transmission has greatly improved the reliability of communications. In addition, the response speed of ZigBee technology is relatively fast .The delay of equipment access to the network is usually 15 to 30 ms. The power consumption of ZigBee technology is extremely low, and two AAA batteries support the use for up to a year. The network capacity of ZigBee technology is large. There can be 255 nodes at most in each coordinator to set up the channel, and each network can hold up to 65535 network apparatuses.

2.2. Zigbee Protocol Architecture

Based on the OSI seven-layer protocol model, the ZigBee protocol combines with the characteristics of the wireless network to form a stack protocol. ZigBee protocol consists of physical layer (PHY), media access control layer (MAC), network layer (NWK), application layer (APL) composition. It is similar to the OSI hierarchy, and each layer provides a specific service to its upper layer.

3. System Design

3.1 Sensor Node Structure

Wireless sensor network node is the basis of the wireless sensor network. Considering the factors such as the monitoring of the growth status of greenhouse tomatoes and the large greenhouse area, a wireless sensor network with one coordinator and multiple terminals is adopted. The terminal includes a sensor module, a processor module, and a signal antenna. The coordinator includes a processor module and a signal antenna serial port transmission module. Depending on the monitoring requirements, different sensors can be used to collect environmental monitoring data such as temperature, humidity and even tomato shapes and colors. The processor is the computing core of the sensor node, which focuses on the functions of device control, task invocation, letter of agreement and data conversion. The signal antenna is used for wireless communication. The serial port transmission module is used to transmit the information received by the coordinator to the host computer. The node working model is shown in Figure 1.

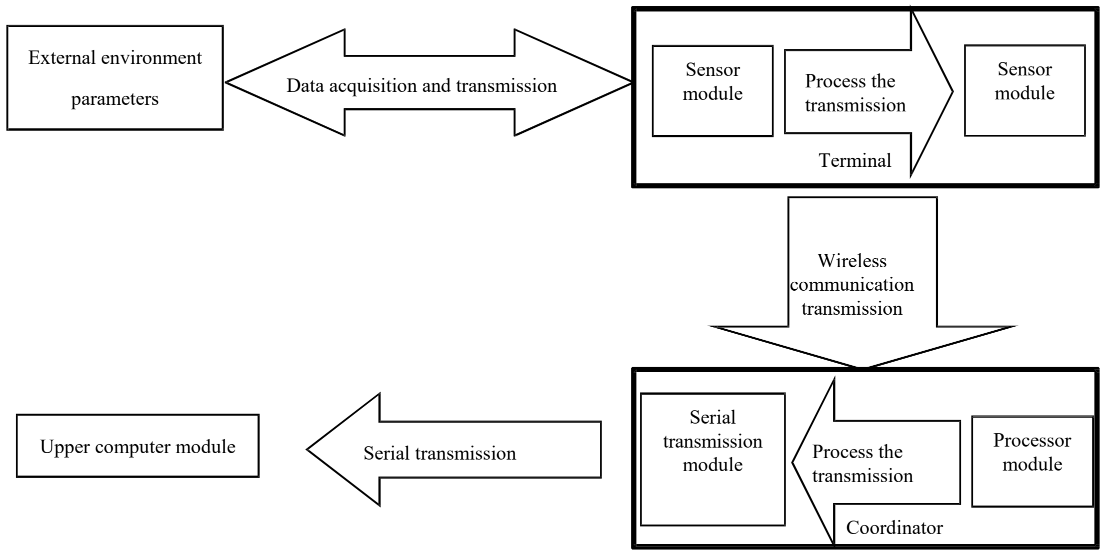

Fig. 1. Node working model

3.2. Sensor Node Hardware Design

3.2.1. Sensor Module Introduction

In the design of tomato growth monitoring system based on wireless sensor network, we can predict the growth of tomato by detecting the temperature and humidity in the greenhouse. Therefore, we select DHT11 temperature and humidity sensor in the system as a node sensor. DHT11 humidity monitoring range of 20% to 90% RH, monitoring accuracy of 5% RH, monitoring temperature range of 0 ℃ ~ 50 ℃, monitoring accuracy of about 1.0 ℃. Its response time is less than 5S, and the sampling period is greater than 2S. Although the monitoring range and precision of the DHT11 sensor are not high, but the growth temperature and humidity of the tomato are relatively constant, the environmental parameters are not much different, and the environmental monitoring does not require real-time and high frequency. Therefore, the DHT11 is very suitable for monitoring the greenhouse of tomatoes.

3.2.2. Processor Introduction

The processor is the computing core of the wireless sensor node, and the processor module focuses on a series of functions such as device control, task invocation, and communication protocol and data conversion. The CC2530 has many powerful peripheral resources such as timers, counters, high-speed serial ports, watchdog timers, DMA, AES-128 coprocessors, 8 inputs and configurable 12-bit ADC and so on. At the same time, CC2530 chip in receiving and sending current loss of 27mA and 25mA, respectively, is an ideal solution for long battery life applications.

3.2.3. Antenna Module Design

Antennas have a great influence on the distance of short-range wireless communication. Gain, impedance matching, bandwidth and size are all important influencing factors. The ZigBee chip CC2530 used in this system are working in the 2.4G band, which is the ISM band. PCB antenna costs lower, while achieving better performance. Figure 2 shows the antenna and baren matching circuit.

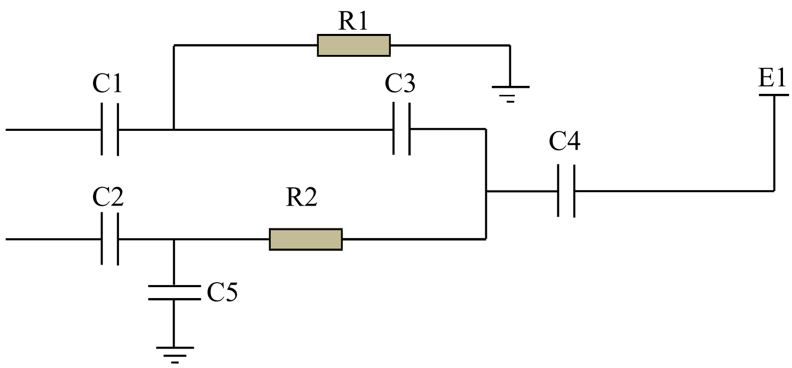

Fig.2. Antenna and Baren matching circuit diagram

3. 2. 4. Serial Port Mode Introduction

In the design of wireless sensor network based tomato growth monitoring system, the coordinator needs to send the received data package to the computer through the serial port to monitor the environmental conditions in the greenhouse. At present, the computer's serial port communication interface adopts the EIA-RS-223C standard. In order to be able to connect with the TTL device of the computer interface or the terminal, the level must be changed between the EIA-RS-223C and the CMOS / TTL circuit. The baud rate, data bits, stop bits and parity bits must be set before communication. For two ports to communicate, these parameters must match. In this system, the baud rate is 115200bps, the data bit is 8 bits, the stop bit is 1 bit, and the parity bit is 0 bit. The serial circuit is shown in Figure 3.

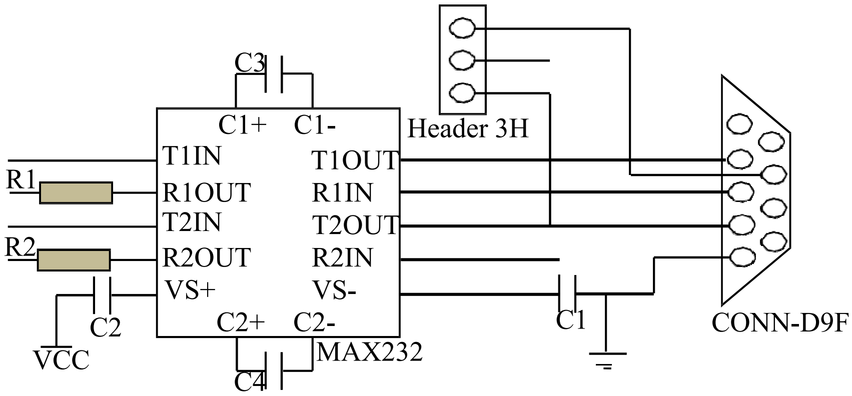

Fig.3. Serial circuit diagram

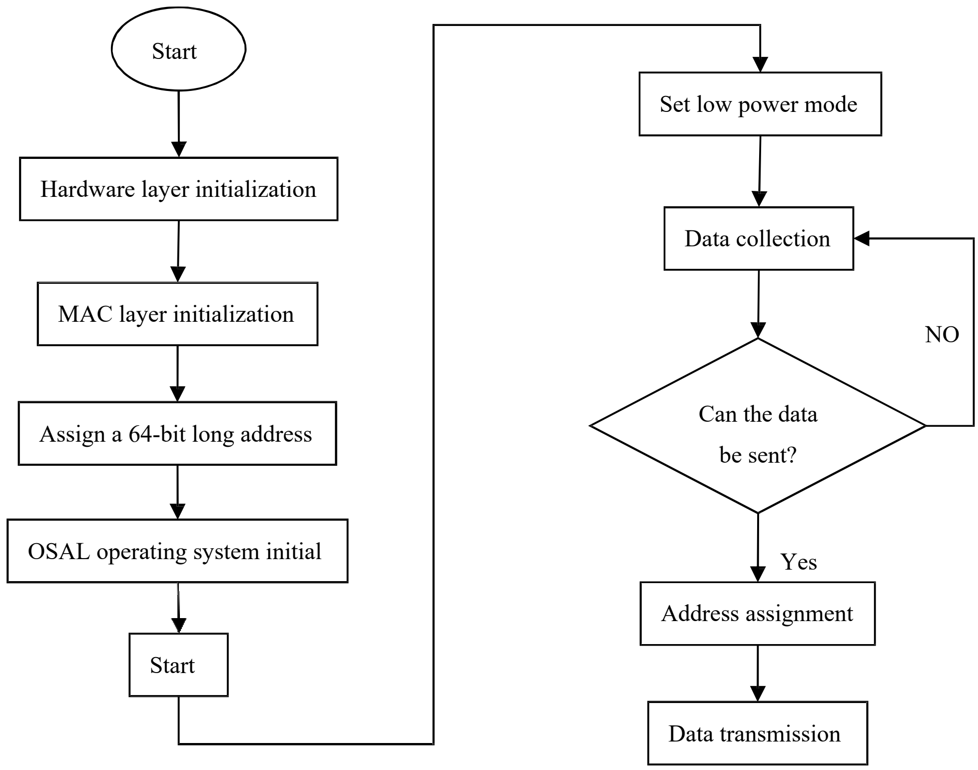

Fig.4. End node program flow chart

3.3. Node Programming

3.3.1 Terminal Node Programming

The role of the terminal node is to collect external environmental parameters, such as temperature, relative humidity of air and soil relative humidity. The node access wireless sensor network to the coordinator transmission of collected data. The node first initializes hardware layer, including the initialization of Stack RAM, initializing the hardware, setting the various parameters. The MAC layer is then initialized, a 64-bit long address is allocated, and a network connection is made. The OSAL operating system is initialized, the interrupt is turned on, and the low power mode is set. After initialization, DHT11 temperature and humidity sensors to collect environmental parameters, send data and requests, respond to send information, complete a collection and transmission of information. Finally, do the task loop. The terminal node flow diagram is shown in Figure 4.

3.3.2. Coordinator Node Programming

Coordinator node's main function is to select a channel and network ID (PANID), starting the entire network, receiving data from the terminal node, the data sent to the host computer through the serial port. The node initially initializes the hardware layer, including initializing the Stack RAM, initializing the hardware, and setting various parameters. Then initialize the MAC layer, activing channel scanning, selecting the appropriate PAN. Then initialize the OSAL operating system, opening the interrupt. After these initialization, the coordinator node receives the sending request from the terminal node, whether the reply can be sent. If request can be allowed, readying to receive data, the data is received after the data transmission through the serial port to the host computer, after the cycle of tasks. The flow chart of coordinator node is shown in Figure 5.

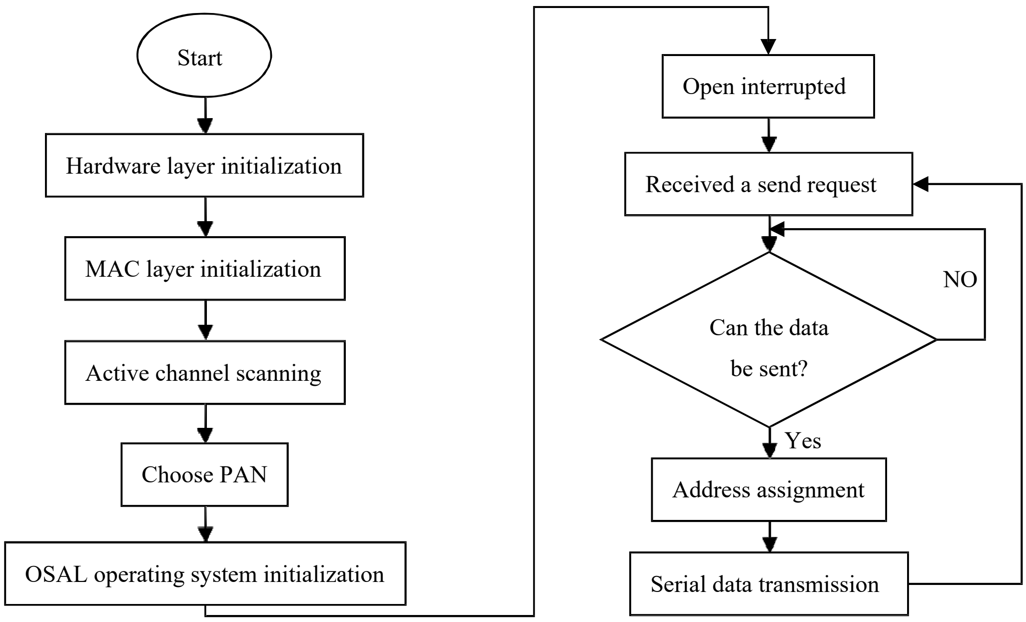

Fig.5. Coordinator node program flow chart

3.3.3. Host Computer Program Design

PC interface design using MATLAB / GUI tools to complete. Various graphical windows, map axes, menus, buttons and other user interface, compared to a large number of VC coding, the use of MATLAB / GUI can significantly reduce the amount of code. Figure 6 for the host computer interface design flow chart, first design host computer interface, the distribution of data display window position, button position, warning message display window. After writing serial read program, and then write interface button callback program, so that each button can play the desired function. Figure 7 is a serial port read program flow chart, first set the serial port parameters in the program according to the serial port, and write an interrupt to receive the number of bytes received in the buffer as an interrupt trigger. After that, continuing to receive data, when the number of characters in the buffer reaches the specified trigger interrupt, reading the buffer area data, then clearing the buffer area characters, repeating the reading process.

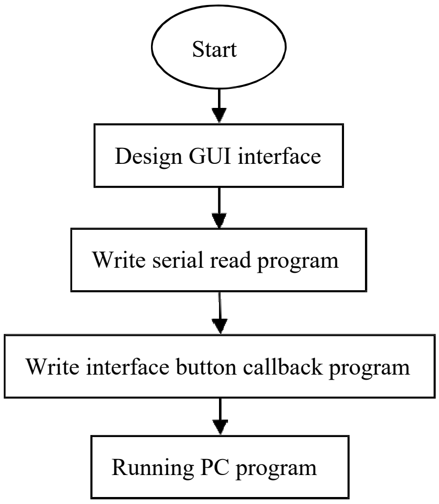

Fig.6. PC interface design flow chart

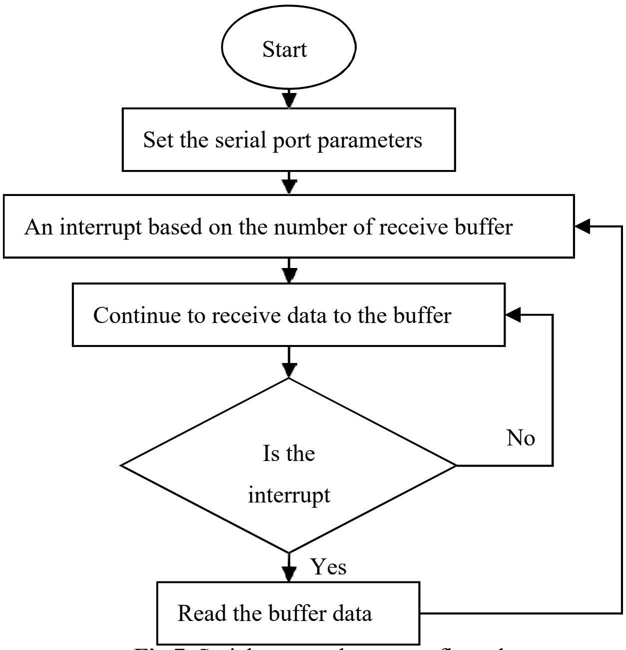

Fig.7. Serial port read program flow chart

Figure 8 for the actual computer MATLAB GUI interface. As shown in the figure, the interface receives information of five nodes, the temperature display window is used to display the data transmitted by the coordinator about the temperature, the humidity display window is used to display the data about the humidity, the warning information window is used to receive the temperature. When the humidity data exceeds a certain range, the information of the node is recorded and displayed in this window.

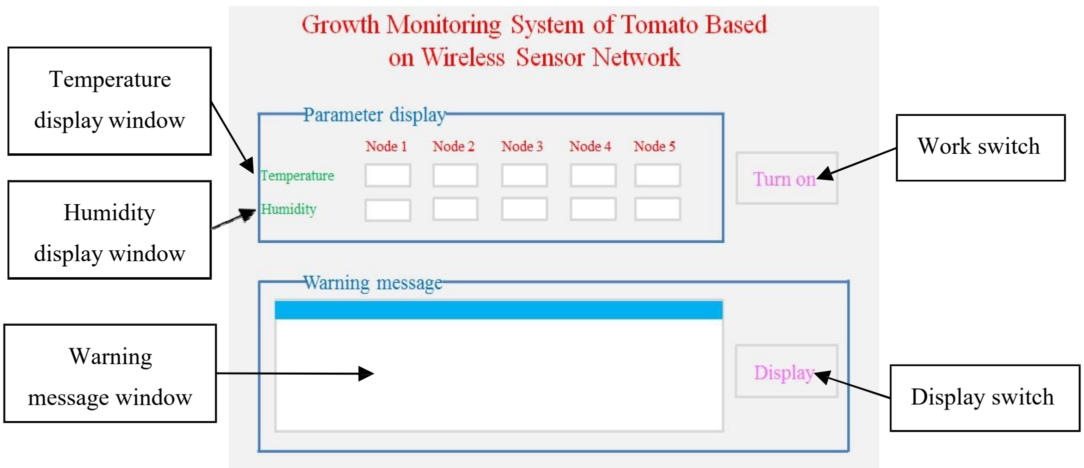

Fig.8. PC actual MATLAB GUI interface

4. Experimental

4.1. The Effect of Node Detection Position

Considering that when monitoring the greenhouse crops, the monitoring height may have an effect on the monitoring. Therefore, it is necessary to understand the influence of monitoring height and location on the monitoring effect before the actual operation. In the experiment, four monitoring locations are set up. As shown in figure 9, a is to place the node on the pelvic floor, b to place the node in the middle of the tomato plant, c to place the node on the top of the tomato plant, and d to arrange the node at a distance from the tomato plant. In the experiments, we selected several plants from different orientations to carry out multiple experiments and conducted several experiments at a, b, c, d and 4 positions to make the experimental data more effective.

a Node in the pelvic floor

b Node on the middle of tomato plants

c Node on the top of tomato plants

d Node at a distance from the tomato plants

Fig.9. Four locations of the node monitoring map

By taking multiple averages for each location and selecting different plants for experimentation, we learned that monitoring for altitude impacts is common across the greenhouse tomatoes. Table1 shows the experimental data, 1, 2 and 3 representing different plants, and the positions a, b, c and d show the above different positions. Each experimental data is the average of the experimental data of the same plant and the same place. Through experiments, get the location and temperature and humidity, in order to select the best monitoring location to place the terminal node.

Table 1 Experimental data sheet

	Temperature1	Humidity1	Temperature2	Humidity2	Temperature3	Humidity3
a	32	39	32	40	31	38
b	31	40	33	42	32	43
c	33	31	33	32	32	29
d	33	24	34	27	35	25

Figure 10 is based on the data processing table to explore the location and measurement of temperature and humidity, which can monitor the height of the impact of temperature and humidity. As can be seen from figure 10, in the experiment of 4 locations in 3 plants, the change of temperature is small, and the overall trend is that the higher the location, the higher the temperature, but less influence. In contrast, the higher the position, the lower the humidity, variations are dramatic, and there is a multiple change in position 1 and position 4. Therefore, the monitoring position of nodes has a great influence on the humidity monitoring. Taking into account the location 4 is susceptible to plant transpiration, to determine the adverse growth of crops, and position 1 suffered little transpiration, so choose position 1 as the monitoring position. After experiments, it is found that the influence of 4 locations on the communication ability of nodes is almost zero, and there is no obvious change in communication distance or communication quality. Therefore, it can be judged that in the greenhouse environment, the node monitoring position is not valid for node communication capability.

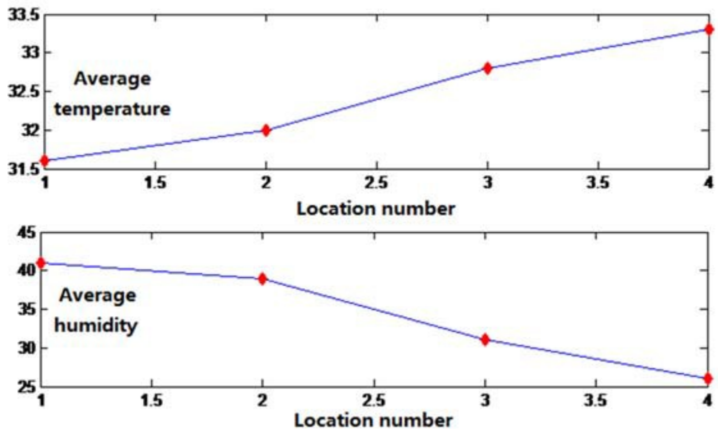

Fig.10. Relationship between location and temperature and humidity

4.2. Wireless Sensor Network Antenna Output Power Analysis

Node signal transmission capacity determines the availability of the entire wireless sensor network, the need to ensure that the terminal node can send monitoring data to the coordinator end. The terminal node antenna output power and communication distance has a close relationship, so the experiment of different antenna output power case to obtain maximum effective distance. The maximum effective distance refers to the maximum distance between the terminal node and the coordinator node in the case that the terminal node and the coordinator node can receive the information of the terminal node during the communication process.

Since the greenhouse is about 28m long and about 10m wide, in order to ensure that the terminal node can send monitoring information to the coordinator node, the experiment will measure the maximum effective distance between nodes can exceed 30m and study the relationship between the maximum effective distance and the antenna output power. Figure 11 shows the relationship between the output power and the maximum effective distance.

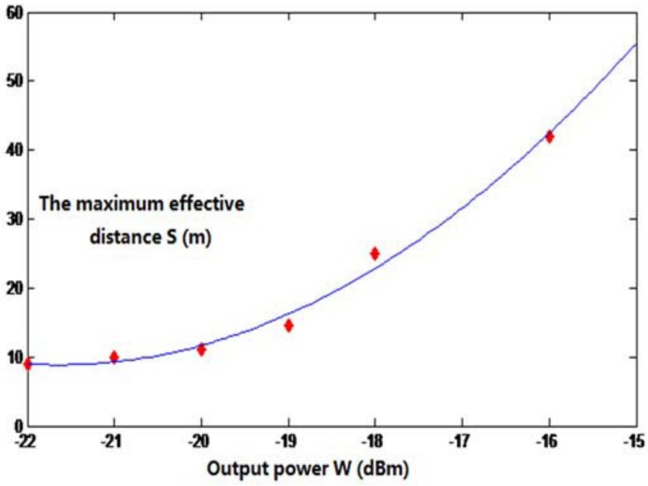

Fig.11. Output power and maximum effective distance diagram

Get the maximum effective distance and the antenna output power of the formula (1):

$$S=W^2+45.8*W+504.7 \quad (1)$$

S is the maximum effective transmission distance, W is the antenna output power.

3.3. Power Consumption Analysis of Wireless Sensor Network

In wireless sensor networks, the power consumption of nodes is an important criterion to measure the availability of the entire system. In the meantime, the battery replacement may not lead to stable operation of nodes in time. In order to minimize the battery power consumption, choose to detect different antenna output power, the terminal node required operating current. Due to the sensor detection during node work, the energy consumed by data processing is not easy to change, so the node working time can be effectively increased by reducing the energy consumed by the terminal node in the communication process. Through experiments, the output power of the antenna of the terminal node is adjusted, and the working current of the node is detected under the condition of different antenna output power. The power consumption capability of the node is measured by detecting multiple times and taking the average value of the detection, and analyze the relationship between the node antenna output power and the working current, as shown in Figure 12.

Get the node operating current consumption and antenna output power of the formula (2):

$$I=0.34*W+30.35 \quad (2)$$

I is the working current consumption of the node, W is the output power of the antenna, and the linearity R is 0.93.

4. System Parameter Selection

Firstly, through the experiment, the influence of terminal node on the measuring effect at different positions, comparing the changes of temperature and humidity by experiment, select the position 1 and place the terminal node at the bottom of the basin. Secondly, the relationship between the antenna output power and the maximum transmission distance is studied. The relationship between the antenna output power and the maximum transmission distance is drawn experimentally. At the same time, the relationship between the transmission power of the antenna and the battery power consumption is experimentally studied. By comparing and analyzing the two graphs, the antenna transmit power is selected according to the distance between the terminal node and the coordinator node. Considering the relationship between the two, in the greenhouse conditions, select -18dBm as the antenna output power, in this case, measure the maximum effective distance of 25m and the node operating current of24.2ma.

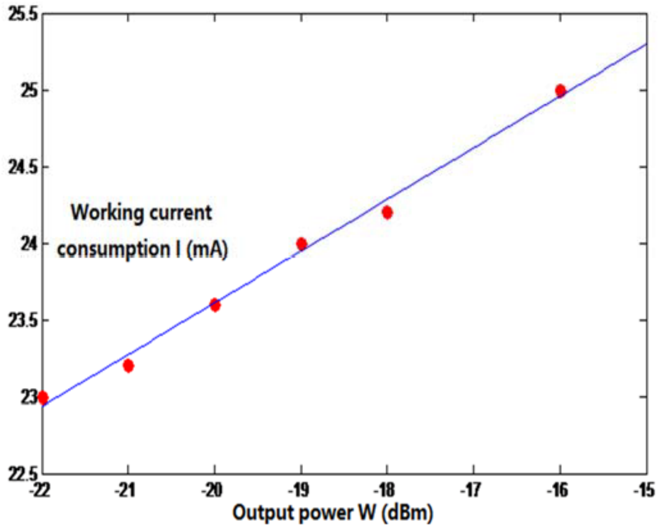

Fig.12. Output power and operating current consumption diagram

5. Conclusion

With the development of technology, the application value of wireless sensor network in life is higher and higher. The application of ZigBee wireless sensor communication protocol is more extensive. The enormous potential of wireless sensor network technology in greenhouse based on agricultural production, solving the drawbacks of high cost, difficult operation, complex wiring and transmission is not stable. In greenhouse tomato planting as an example, the ZigBee wireless sensor network for greenhouse tomato growth is used to monitor. In order to better use the ZigBee technology in the greenhouse agriculture. The research contents of this paper are as follows:

(1) The protocol system of ZigBee technology is analyzed, and the hierarchical relationship of the ZigBee protocol is clarified.

(2) The hardware composition of the node is introduced, DHT11 is selected as the node sensor and the CC2530 chip is selected as the processor module.

(3) This paper introduces the design of greenhouse tomato growth monitoring system based on wireless multi-sensor fusion, the design of the bottom system of nodes, the program of node data acquisition, the program of data transmission between nodes and the realization of serial communication.

(4) The upper computer designed for the greenhouse tomato growth monitoring system based on wireless multi-sensor fusion was designed, and the interface was designed with MATLAB/GUI.

(5) Experiments were conducted in greenhouse to explore the influence of monitoring location on monitoring effect, the relationship between output power and maximum effective distance of antenna, and the relationship between antenna output power and working current, which is good for monitoring greenhouse in the future.

Acknowledgments

This research was financially supported by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), Development Plant of Zhenjiang to Modern Agriculture (NY2015026) , Jiangsu University Students Practical Innovation Training Project (201710299244W) and Jiangsu University Students Science Research Project (16B015).

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