Digital Greenhouse System via WSN*

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Abstract. The paper designs an agricultural digital greenhouse system via Zigbee+GPRS. Environmental sensors and CC2530 RF chip as the core designs a series of nodes collecting information in greenhouses. These nodes generate networks based on ZigBee protocol, Environmental parameters and real-time images upload to a centralized monitoring host for analysis, storage and display via GPRS. In order to improve the network stability and extend the life of the network, this paper uses SDT algorithm to avoid redundant data transmission, and optimizes image acquisition through the frame difference method. The objective of the study, can change the straightforward way of greenhouse crops, achieve accurate, intensive, intelligent cultivation, increase production, reduce cost, and promote the WSN application in the field of agriculture.

Keywords: Digital Greenhouse, ZigBee, CC2530, SDT, WSN.

1 Introduction

Wireless Sensor Network (WSN), a combination of sensor technology, embedded computing technology, modern networking, wireless communication technology and distributed information processing technology, is widely used in the agricultural greenhouse, through various integrated micro-sensors to monitor real-time collaboration, perceive and collect a variety of environments or monitor objects [1].

Agricultural greenhouses can grow a variety of vegetables and fruits, while not subject to seasonal constraints. inside carbon dioxide concentration, temperature, humidity and light intensity directly affect the growth of plants, besides greenhouses are generally not set up in urban areas, which leads to the high cost of human duty and weakness of real-time, requiring remote monitoring greenhouse environment parameters and real-time images. Zhang Qibo etc. designed the remote AD590-based digital display temperature measurement and control instrument [2]. Li et al. designed ZigBee and embedded system based greenhouse temperature monitoring system [3]. Li Mingjun who used GPRS communication technology designed the greenhouses intelligent monitoring system [4].

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those systems, achieved remote monitoring, had their own strengths with different technical methods, but did not explain the actual problems encountered while deploying and solutions, For example, in large-scale deployment of nodes, how to solve data congestion problem, how to upload pictures to use less traffic and not occupy the bandwidth heavily. GPRS is relatively narrow bandwidths, the system should ensure that the most useful data prior to upload.

This paper first introduces carbon dioxide concentration acquisition node and temperature-humidity acquisition node and light intensity acquisition node design, and then summarizes the approaches to reduce power consumption and to optimize the network, and finally discuss how to implement remote monitoring.

2 System Design and Implementation

The system, using a ZigBee protocol [5] widely used in WSN and drawing on experiences in domestic and international agricultural digital greenhouse system, designs system architecture shown in Figure 1, where E1, E2 represent information collection node, including carbon dioxide concentration and temperature and humidity, etc. some routing nodes can be properly deployed if necessary.

According to ZigBee protocol stack architecture [6], this system can be divided into three layers, the sensing layer can be thought of IEEE 802.15.4 MAC layer protocol and physical layer is responsible for collecting information and send to coordinator node (the routing node may be routed through), which forwards the data to the gateway, the gateway extract useful data added greenhouses unique information to sent to the monitoring host, which puts the data into the appropriate location for remote viewing based on the greenhouses information.

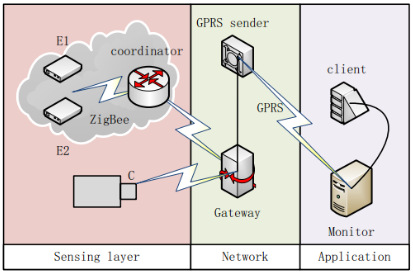

Fig. 1. System framework

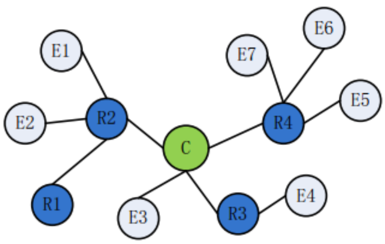

Fig. 2. Topology structure

ZigBee network in this system includes a coordinator node, some routing nodes and data collection nodes. Routing nodes simply responsible for the data transfer can be removed if the greenhouse area is not large, furthermore, the controlling nodes, such as ventilation control, humidification control, etc, only need to connect a digital switch, will not be described here. The paper talks about the hardware and software design and implementation only for the coordinator node and data collection nodes.

2.1 Coordinate Node

ZigBee as an ad hoc network has a clear distinction with WiFi, which has huge energy consumption and weakly supports for multi-hop, WiFi networks usually setup for star structures, while ZigBee has a wide range of simple routing algorithms and fast data transmission features [7], and more for the structure shown in Figure 2, where C is representative of the coordinator node, Ri represents the routing nodes, Ei represents the data collection nodes.

In a ZigBee network, each node has two addresses, a 64-bit IEEE extended address and a 16-bit network address [8] which is allocated by the parent node in the network when the node joins. The short address effective internal is used to maintain the network structure, while the 64-bit long address is the modifiable hardware address, an external unique identifier for the node.

Each parent node can connect upto C_m child nodes, in which R_m sub-routing nodes exist at most; the maximum depth of the network is L_m. When a data acquisition node without routing functionality comes to the network, the depth of its parent is d, and the node is nth child, then the node's short address A_n can be calculated according to formula (1) [9], where A_k is the parent node's address, $Cskip(d)$ indicates address offset that the parent node with depth of d assigns to its child.

When a routing node joins the network, its network address An is calculated according to formula (2) [9]. In the formula (1), (2) the $Cskip(d)$ is calculated by the equation (3) [9].

$$A_n = A_k + Cskip(d) \times R_m + n \tag{1}$$

$$A_n = A_k + 1 + Cskip(d) \times (n-1) \tag{2}$$

$$Cskip(d) = \begin{cases} 1 + C_m \times (L_m - d - 1) & , if R_m = 1 \\ \frac{1+C_m-R_m-C_m\times R_m^{L_m-d-1}}{1-R_m} & , otherwise \end{cases} \tag{3}$$

According to the formula (1), (2), (3) the system calculates the communication address of each node. The coordinator node records all of the addresses in the network to maintain the dynamic changes of the network to ensure that the data collected is sent correctly to the application layer.

2.2 Carbon Dioxide Concentration Acquisition Node

(1) Hardware Structure

Part circuit of the carbon dioxide concentration node shown in diagram 3 includes CC2530 RF chip, MG811 carbon dioxide concentration sensor (amplified output signal), the power supply circuit and a reset circuit. MG811 output analog signal to the ports P0, CC2530 obtains the digital correlation values of the carbon dioxide concentration through a build-in analog-digital converter. MG811 solid electrolyte sensor is working properly when core temperature grows up to 500 degrees, while the kernel and the surrounding air is in direct contact, so the ambient temperature changes can affect the sensitivity of the sensor, and tCOM port is used to solve the problem of the temperature compensated output.

The data sheet of MG811 writes that this type of CO_2 sensor has good sensitivity and selectivity; is weakly affected by temperature and humidity changes; has good stability and reproducibility. MG811 is a solid electrolyte sensor, whose signal output impedance is very high, which means it is not a good idea to measure the output signal directly with the common voltmeter or multimeter. Add a termination impedance conversion circuit in the sensor output signal level when designing, which can reduce the output impedance to normal measurable level, the impedance conversion op amp must use high input impedance type, say CA3140.

(2) Software Design
Figure 4 shows the relationship between EMF and the concentration of carbon dioxide with a temperature of 28, relative humidity of 65%, and an oxygen concentration of 21%, wherein EMP represents the potential difference between the sensitive electrode and the reference electrode, the variable is in accordance with the Nernst equation:

$$EMP = E_c - (R \times T)/(2F)\ln^{P(CO_2)} \tag{4}$$

$P(CO_2)$ shows the carbon dioxide partial pressure, E_c is a constant, R is the gas constant, T is the absolute temperature, F is the Faraday constant.

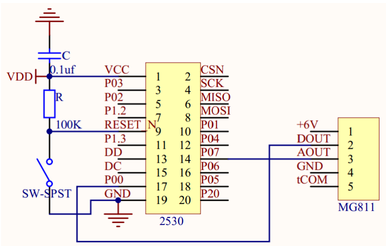

Fig. 3. Circuit diagram of the carbon dioxide concentration acquisition node

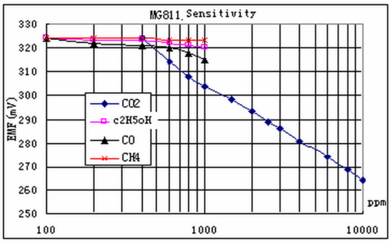

Fig. 4. MG811 Sensitivity

MG811 output is an analog signal (amplified) 0V∼2V, from Figure 4 (the original signal) can be seen the lower the concentration the higher the output voltage. Generally normal clean air contains CO_2 350ppm. In order to get a more accurate value, the system need MG811 temperature compensation output, when the ambient temperature changes, the output voltage signal changes therewith, which means the temperature change amount is converted to the corresponding output voltage variation, and thus through the program to compensate for the temperature change.

2.3 Temperature and Humidity Acquisition Node

(1) Hardware Structure
Part circuit of temperature and humidity acquisition node shown in Figure 5 comprises CC2530 RF chip, SHT11 temperature and humidity sensors, power

supply circuit and a reset circuit. SHT11 using I2C interface, where VDD is the power input with the scope of 2.4V~5.5V, GND is ground, SCK is the serial clock input, connected with the CC2530 SCK, DATA is the serial data line, two-way transmission. As long as add I2C interface program to the CC2530, the system can collect temperature and humidity.

(2) Software Design
SHT11 requires a timing sequence Start Transfer shown in Figure 6 before sending a command: When SCK is high DATA toggles low, followed by SCK goes low, then DATA flip to high with high SCK. After that the address code and instructions are required, the address currently only can be 000, temperature directive 00011, humidity directive 00101, followed by the 8th SHT11 SCK clock after whose falling edge the DATA drops down (ACK bit) until the 9th SCK clock falling edge (recovery high), indicating that the command has been completely sent, the rest is waiting for data to return. If necessary, reset the connection according to the timing sequence shown in Figure 7.

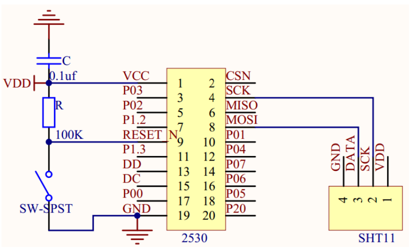

Fig. 5. Circuit diagram of the temperature and humidity acquisition node

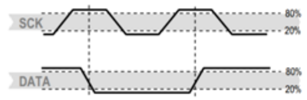

Fig. 6. Start Transfer

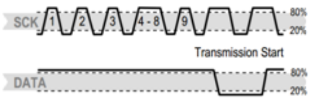

Fig. 7. Reset sequence

2.4 Light Intensity Acquisition Node

(1) Hardware Structure
Part circuit of light intensity acquisition node shown in diagram 8 comprises CC2530 RF chip, TSL2550 light intensity sensor, the power supply circuit and a reset circuit. TSL2550 uses SMBus interface, where VDD is the power input with the scope of 2.7V~5.5V, GND is ground, SMBCLK is the serial clock input connected to the CC2530 P0.0 pin, SMBData is a two-way transmission data line. the system can capture the light intensity, adding SMBus interface code the CC2530.
(2) Software Design
TSL2550 is a kind of light sensor with two wired digital output, a built-in 8-bit command register is used to configure the sensor with the command format shown in Figure 9, where S and P represent the start and end, WR is 0, A represents ACK . In addition, TSL2550 has two read-only data registers, which memorize channel 0 and channel 1 collected light intensity separately, users read channel 0 (1) need to set the command register 0x43 (0x83), read data command format is shown in Figure 10, where RD is 1.

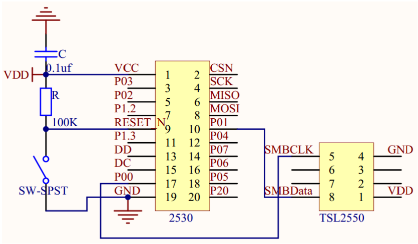

Fig. 8. Circuit diagram of the light intensity acquisition node

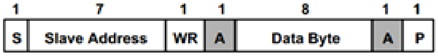

Fig. 9. Read Command

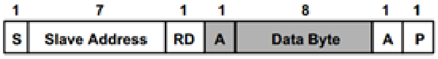

Fig. 10. Write Command

3 Reducing Power Consumption and Network Optimization

So far, the system has been able to work correctly, but once mass nodes deployed, the system will encounter problems of network congestion and power consumption, the following will describe how to overcome these problems and ensure the normal operation of agricultural greenhouses.

3.1 Utilizing SDT Algorithm to Avoid the Redundant Data Transmission

It is obvious that environmental parameters in the shed are actually process data, that contains a lot of redundant information, which information loss will not affect the overall distribution of data and trends, and then there is no need to spread in the network, a way affect network bandwidth, the other increase the pressure of the coordinator node. For example, a one-hour time change of the temperature in the greenhouse is actually not very large, but does not rule out a sudden change, which means it should ensure those significant changes in the data uploaded successfully but imperceptible changes discarded.

In this paper, the idea of SDT algorithm [10] is used to avoid redundant data transmission. SDT algorithm is a compression algorithm with linear trend, for a given data, first specify the maximum permissible errors, such as temperature error is 0.3, and then locate the trend line as long as possible, so when the temperature and humidity collection node returns the temperature, compare with the last upload, if the error is less than 0.3, discard the data after collection or else upload temperature, meanwhile refresh the temperature profile with the collection about the last upload, reserved for the next reference.

Figure 11 shows the effect of using SDT to avoid the transfer of redundant data in one hour, where a red dot indicates the temperature taken every minute, and blue represents the actual temperature uploaded, each covers a red point, so there are 60 red dots and 32 blue dots, then the actual amount of data transferred only 53% of the original, greatly reducing the pressure on the network. Of course, the actual efficiency of the method and pace of environmental change has a direct relationship, if the environment changes dramatically (greenhouse rarely encountered), this method is not very obvious; but if the environment changes slowly (in most cases this is) the method effect is quite significant.

3.2 Utilizing Frame Difference Method to Reduce the Image Transmission

The system uses GPRS to upload real-time images, but in the actual process, uploading an image in regular intervals will be bandwidth-intensive, which will affect other environmental parameters upload for inherently narrow bandwidth of GPRS, taking advantage of inter-frame difference method which get rid of the image frame not changed obviously can reduce the amount of data uploading.

Frame difference method [11] first determines a grayscale threshold T, then the formula (5) is calculated to get binary image $D(x, y, t_i)$, where (x, y) represents pixel, $F(x, y, t_i)$ represents the pixel in the gray value at time t_i.

Then, using equation (6), the equation (7) calculate the accumulated value sum and the cumulative num of the motion area, to obtain the mean gray level difference $avg = sum/num$, then upload the image when avg is greater than the error threshold T_{avg} and update $F(x, y, t_{i-1})$, or else do not have to upload the image.

$$D(x, y, t_i) = \begin{cases} 0 & , |F(x, y, t_i) - F(x, y, t_{i-1})| < T \\ 255 & , |F(x, y, t_i) - F(x, y, t_{i-1})| \geq T \end{cases} \tag{5}$$

$$sum = \begin{cases} sum + |F(x, y, t_i) - F(x, y, t_{i-1})| & , D(x, y, t_i) = 255 \\ sum & , D(x, y, t_i) = 0 \end{cases} \tag{6}$$

$$num = \begin{cases} num + 1 & , D(x, y, t_i) = 255 \\ num & , D(x, y, t_i) = 0 \end{cases} \tag{7}$$

3.3 Using Active Transport to Reduce the Query

In the process of data collection program query response mechanism is commonly used, namely, data collection node always listens air signal for the requests from the coordinator node, then performs data acquisition and replies to the coordinator node, after that gets into the listening state again, reason for doing this is by reducing computation amount of data collection nodes to reduce power consumption, however, in the system with real-time requirements that increases the coordinator query data packets, which gives the coordinator node too much pressure.

Aimed at the situation above, the flowchart shown in Figure 12 is designed for the data acquisition nodes, compared with the query response mechanism the program increases the collection times, but thanks to the approach in section 3.1 , the system not only does not increase the number of packets in the network, but also leaves the network more fluently because of removing the regular query program in the coordinator node; in addition, the method of using the hardware timer interrupt to trigger data acquisition saves excessive loss of energy.

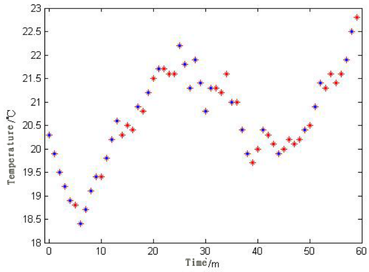

Fig. 11. Effect of utilizing SDT algorithm to avoid the redundant data transmission

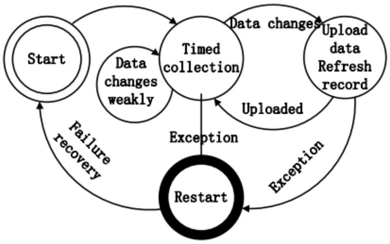

Fig. 12. Data acquisition node work flowchart

4 Teleprocessing Monitor

First, open a remote host port (non-80 port) for GPRS upload data, each shed has a GPRS transmitter node for uploading real-time environmental parameters and images, these uploaded data package contains the unique identifier of the greenhouse character, when the remote host receives the packet, the identifier will be extracted and bind to the TCP connection which received the packet. If there is a previously bind, but different from the new connection (GPRS reconnection), the system releases the bound TCP connection and creates a new bind between the identifier and the accepted TCP connection. With this binding relationship, the remote host can send arbitrary commands to arbitrary greenhouses, such as ventilation, humidification. Figure 13 and Figure 14 is physical pictures of data acquisition nodes.

Users authenticated to access the remote host can see the information of their own greenhouses (the user has been registered by greenhouse identifier), for example, a user registered three greenhouses where planted strawberries, vegetables and pineapple separately, then he will see the screen shown in Figure 13, which includes selection buttons left of the greenhouses (vegetable is selected), and the live image and environmental parameters in the middle, as well as the control buttons right side (currently vegetable greenhouse is heating up and adding carbon dioxide).

5 Comparison and Analysis

Agricultural digital greenhouses can provide people vegetables and fruits regardless of seasons, it is a life-changing paradigm, and what makes it different from traditional greenhouses is that it can save human resources, people at work can feel the joy of farming at the same time, and this system compared with other similar systems has the following characteristics:

(1)Low cost, low power consumption All nodes used are of modular design, the deployment amount can be specified according to the size of the greenhouses,

Fig. 13. Temperature and humidity node

Fig. 14. Carbon dioxide concentration node

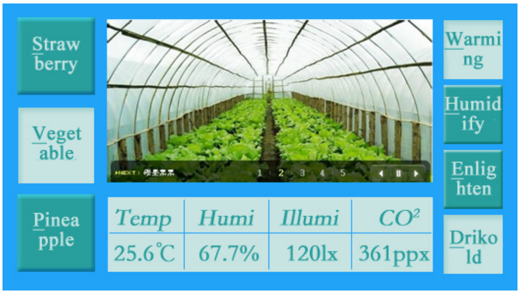

Fig. 15. Overall effect screenshots

data acquisition using the interrupt mode, reducing the number of queries, cutting the ZigBee protocol stack by removing some of the complexity not commonly used, can reduce power consumption as much as possible, making the network run more smoothly and long lasting.

(2)Multi-function integration The system can not only collect temperature, humidity, light intensity and carbon dioxide concentration, but also real-time images, allowing users to keep abreast of greenhouses state. In addition users can connect to the server through the greenhouses binding way, which allows users to control greenhouse environment remotely, eliminating the tedious manual operation. So many features can be integrated together is one of the characteristics of the system.

(3)Deploy a larger scale Using the idea of SDT algorithm creates more intelligent data acquisition node so that it can independently determine whether the data is uploaded, thereby reducing data transmission frequency, which greatly optimizes network performance, so that the network can accommodate naturally the number of nodes increase, by contrast, the system can be deployed in greater greenhouses in agriculture.

(4)Real-time feature Considering the cost of the long-distance wireless communication, GPRS is a reasonable choice only, but low bandwidth leads the transmission of video basically unrealistic, transferring images which in turn produces the real-time constraints, from this viewpoint, in this paper, inter-frame difference method is capability of both low cost and real-time.

6 Conclusion and Prospect

In this paper, ZigBee technology, GPRS network and B/S mode are used to build a digital greenhouse system to achieve environmental acquisition, image acquisition and remote monitoring capabilities, meeting the requirements on low-cost and automated agriculture, but the system also have sustainable space of development, such as applying 3G/4G technology to provide more comprehensive data services, converting the image acquisition into a video capture; introduction of agricultural research parameters, so that the greenhouse can automatically adjust to fit the greenhouse crop growth, reducing labor participation; increasing the data collection nodes to gain more refined figures and so on.

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