Design of Wireless Sensor Network-Based Greenhouse Environment Monitoring and Automatic Control System

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Abstract—**In view of the characteristics of greenhouse environment monitoring system, a system scheme based on wireless sensor network (WSN) is presented, which adopts Atmega128L chip and CC2530 that is a low power RF chip from TI to design the sink node and sensor nodes in the WSN. The monitoring and management center can control the temperature and humidity of the greenhouse, measure the carbon dioxide content, and collect the information about intensity of illumination, and so on. And the system adopts multilevel energy memory. It combines energy management with energy transfer, which makes the energy collected by solar energy batteries be used reasonably. Therefore, the self-managing energy supply system is established. In addition, the nodes deployment method and time synchronization problem are analyzed in detail. The system can solve the problem of complex cabling with the advantages of low power consumption, low cost, good robustness, extended flexible and high reliability. An effective tool is provided for monitoring and analysis decision-making of the greenhouse environment.**

Index Terms—**wireless sensor networks, AVR single chip microcomputer, greenhouse, time synchronization, nodes deployment**

I. Introduction

The greenhouse agriculture is developing very fast with the increasing demand of fresh vegetables in the large and medium cities. It is a kind of place in which it can change the plant growth environment, create optimum condition for plant growth, and keep out of the environment changes and the influence of atrocious weather [5-6]. On the basis of making full use of natural resources, greenhouse monitoring system obtain the optimum condition of plant growth by changing the factors of greenhouse environment such as temperature, humidity, intensity of illumination, carbon dioxide content and so on, and the purpose is to increase crop yield, improve its quality, regulate growth cycle, improve economic benefit. Greenhouse monitoring system is a complex system, the different kinds of parameter in the greenhouse needs automatic monitoring, information processing, real-time control and on-line optimizing.

In recent years, the greenhouse industry has got greater progress, and improved agricultural labor productivity. However, we have quite big difference with developed country in control system area. On the one hand, the introduction costs of foreign advanced control system are too high, and most of them are not suitable for the national conditions of our country; on the other hand, The vast majority of existing control technology and equipment are backward in the domestic, equipment types is too simple, environmental regulation is limited, and it is difficult to popularize application. Therefore, the greenhouse control system that adapt to the development of China's greenhouse production would be developed [20-21].

At present, the greenhouse cable monitoring system is relatively mature, the network topology structure evolved from that of centralized to that of distributed, for example, RS485 based measurement and control system is a centralized structure and Field-bus (CAN BUS, PROFIBUS, LONWORKS, and so on) based measurement and control system is a distributed structure. Although the system’s functions are more and more decentralized and the system has more and more distance [18-20], the most of greenhouse data acquisition systems adopt the wired collection way which is factitious or prewired. The workload is increased and real-time and validity of the data cannot be guaranteed by means of artificial. The monitoring control system which adopts the wired collection way is influenced by geographic position, physical circuit and complex environment and it is bounded clearly. With the appearance of low cost, low power dissipation sensor and the development of wireless communications technical, it is time to construct wireless greenhouse monitoring system, this will have great real-significance to realize agricultural modernization [2-4]. According to the requirement of collecting greenhouse environmental message quickly and accurately, this paper explores deeply at some aspects, such as greenhouse

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environmental message collection, dispose, transmission, release and so on, and the greenhouse monitoring system based on WSN is introduced. Lots of the Sensor Nodes are deployed randomly in the monitoring area, the tiny Sensor Nodes which have the ability of wireless communication and data-handling constitutes the distributed intelligence monitoring net which can complete the appointed mission by self-organization network, and use the synergic way to achieve perception, collection and handle the environmental message covered by the net, then use the multi-hop way to transfer the detecting data from Sensor Node to Management Node by Sink Node link. Contrarily, by means of Management Node, user could proceed to deploy and supervise, publish and monitor assignment, collect monitoring data for WSN [1]. This system has high practical value to realize information and automation of large-scale greenhouse monitoring and improve work efficiency.

II. THE OVERALL STRUCTURE OF THE SYSTEM

The greenhouse environment monitoring system based on WSN includes monitoring centre, sensor nodes and control equipments. Sensor nodes are deployed in greenhouse wherever, and preside periodic collection greenhouse environmental message and transmit to control centre, it is constituted by Sink Node, Relay Node and Sensor Node. These data are handled and analyzed when control centre gains, then relevant decisions are made and send control message to greenhouse control equipment, which regulate greenhouse environment parameters to obtain best growth environment for crops. Modern greenhouse has very large size, and which adopt hierarchical system structure. Supposed that greenhouse is rectangular area, the measurement system overall structure is shown in Fig.1.

The greenhouse was divided into several same area of greenhouse, each measurement and control area is managed by a base station, and is divided into many virtual grids and is non-overlapping. A number of sensor nodes are deployed in virtual grid and make a cluster, each cluster includes a cluster head (sink node) and some cluster member nodes. Cluster head generated from the member nodes through cluster head election algorithm, and cluster member nodes compose of sensor nodes which can collect environmental data and control nodes which can control actuators and adjust environmental parameters. Control node does not participate in cluster head election, it obtain command which the monitoring center send from cluster head node and execute corresponding control operation. The star network composed of Cluster head nodes, sensor nodes and control nodes, it mainly complete data acquisition and control of greenhouse environment. The data which is collected is transmitted directly from sensor nodes to cluster head, the cluster nodes transferred data to the base station by way of multiple hops, at last, the base station transferred each cluster head node data which is packaged to the monitoring center. Base station is relay station between the monitoring center and greenhouse WSN nodes, the network control is realized by managing all the nodes of single greenhouse measurement and control area. The monitoring center is not only total console of more greenhouse network, but also data center of measurement and control system of the greenhouse network , and take charge of control and management of the entire system.

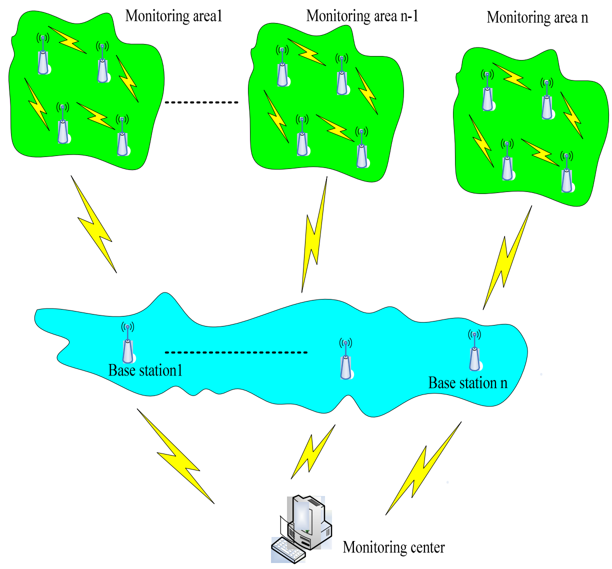


Figure.1The system structure of Greenhouse WSN measurement and control

III.GREENHOUSE WIRELESS SENSOR NETWORK NODES DESIGN

Sensor network nodes are objects which are deployed in study areas of WSN, in order to collect and forward information, and accomplish specified task. Therefore, every Sensor Node has not only collect and process data, but also the function of wireless communication. Greenhouse wireless sensor network monitoring system consists of two types of nodes, sensor nodes and sink nodes. Sensor nodes consist of processor module, wireless communication module, power supply module, sensor module and position setting switch which set physical location information of itself. Sink nodes consists of processor module, wireless communication module, continuous power supply module and serial interface communication module.

A. Sensor node module design

Sensor nodes mostly make up of processor module, wireless communication module, sensor module, switch of position setting and energy supply module. Its structure is shown in Fig.2. Sensor module is in charge of information collection and data conversion in monitoring area, according to the application requirements, it can select temperature sensor, humidity sensor, light sensor, carbon dioxide concentration sensor and so on. Processor module takes charge of controlling the operation of all the sensor nodes, storing and disposing the collection data of the node or forwarded by other nodes; Wireless communication module is responsible for wireless communication, exchanging control information and transceiver acquisition data between this node and other nodes. Position setting switch is used to set a sensor node specific physical location in greenhouses. Energy supply module can provide energy which the work need for sensor node, in the paper, we adopt solar self-supply module for node power supply.

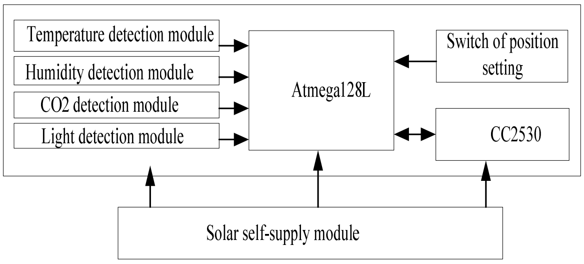


Figure.2 Sensor node structure chart

B. Sink node module design

Sink node mainly complete the sensor nodes data gathering and fusion within communication network, and realize ascending and descending communication protocol conversion. It released monitoring task of management nodes, and the data collected is forwarded to the external network through a serial port. It is not only an enhanced sensor node, but also special gateway device which hasn't monitoring function and only has wireless communication interface. Its structure is shown in Fig.3. It consists of power system, memory module, processor module, node communication module, serial interface communication module and so on. Because sink nodes need to handle a lot of data of sensor nodes, and have longer work time and shorter sleep time, energy of battery cannot enough to energy consumption of sink node, therefore, the project of solar power self-powered module of sink nodes is adopted in the paper.

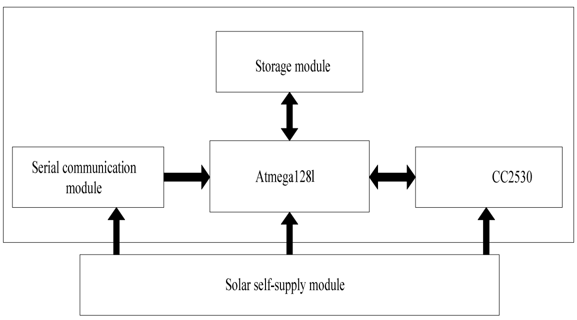


Figure.3. Sink node structure chart

C. Solar power collection and energy management module

In order to solve the problem of energy supply of sensor nodes, we adopted solar energy supply system in the paper, and the structure is shown in Fig. 4. Fig.4 show that power supply module have energy collector, energy storage, backup energy memory, power management and control section. Energy collector consists of solar panels, and is responsible for transforming the solar energy into electrical energy; energy storage includes the main level of energy stored, consists of super-capacitor, it is responsible for storing the collected solar energy and supply power for wireless sensor nodes; back-up energy memory formed by a lithium battery, in the practical application, Lithium-polymer battery is adopted to supply power in the long absence of light or in case of emergency for the system; power management and control section are responsible for monitoring the primary and secondary energy memory and energy state of back-up energy memory, according to state, energy memory is used to supply for the system and control solar energy to add energy for itself. In this system, the polymer lithium battery capacity is 300mA.h, in practical applications, according to actual situation, chose adequate capacity battery [11]. Power supply performance test that sensor nodes continuously work for 1d is shown in Fig.5.

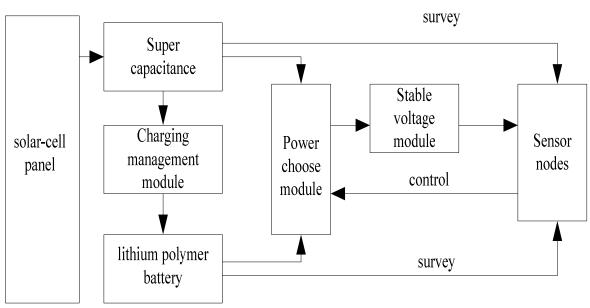
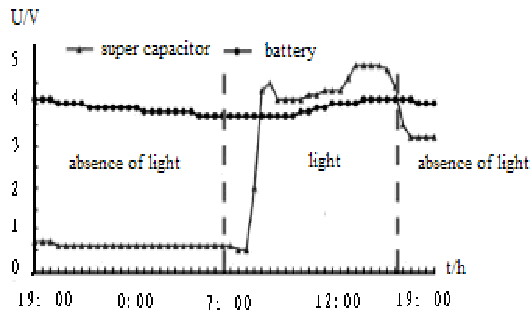
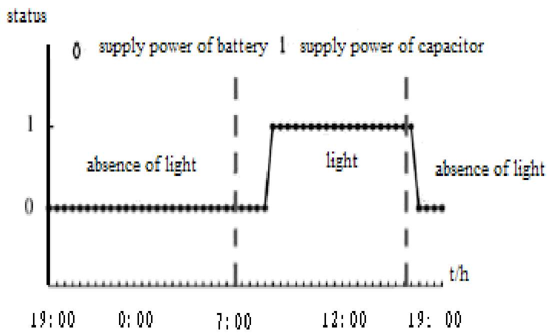


Figure.4. Solar self-supply module structure



(a) The voltage curve of super-capacitors and polymer lithium battery



(b) Power supply switch

Figure.5 Power supply test of sensor node

IV. SYSTEM SOFTWARE DESIGN

A. Software Design

Modular design thought is adopted in system software program which mainly composed of data collection system of the greenhouse and wireless control systems. The data acquisition system uses wireless sensor nodes to collect information of the surroundings, and transfer data to the sink node by means of combining the wireless network; then sink nodes sent the data which are fused to the controller; in the same time, the sink node receives instructions from controller, and forwards the command to the sensor node again. The workflow of system software is shown in Fig.6.

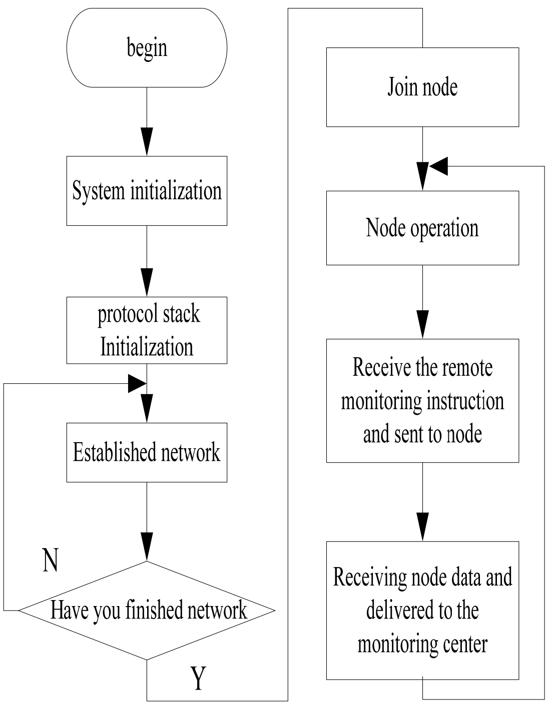


Figure.6 System software flowchart

B. Problem of nodes deployment

Integration of sensor technology, data processing and communications technologies such as wireless sensor networks has been great attention by all researchers, it also is moving node intelligence, miniaturization and large-scale network of direction, but as a distributed system, the support of a reasonable node deployment and time synchronization is very necessary. In a distributed system, different Sensor Node has its own local clock, temperature changes and the different environment will make the node clock frequency drift. Even if each node achieves time synchronization at a time, after it has longer work hours, due to frequency drift, the node will accumulate a certain clock skew, and it is inconsistent with the clock of reference node. Therefore it needs to have a good time synchronization mechanism to ensure clock synchronization between each node and the reference nodes. Especially in sensor networks, time division multiple access (TDMA) and multi-node data fusion technology all need a good time synchronization mechanism.

1. Cluster network formation

Existing WSN clustering algorithm, LEACH is a clustering algorithm which is more mature and commonly used [12], but it is the uniform clustering, some nodes of the low energy at the edge region may also be selected as cluster head, at this time their energy will soon be exhausted, and bring about that the network can not function properly, so this paper adopt non-uniform cluster head election algorithm based on LEACH to form a cluster structure of the network.

2. Cluster head selection

A fully distributed mechanism is adopted, the sensor's working process is divided into periodic rounds, each round consists of two stages, that is, cluster the establishment phase and stable phase. Algorithm can guarantee that have bigger probability to take node which has a large residual energy as the cluster head, and it extends the network lifetime. Suppose that threshold is $T(n)$, and nodes generate a random number between 0 and 1, if $T(n)$ is smaller than the random number, it is the cluster head node of current round. The settings of $T(n)$ are as follows.

$$T(n)=\begin{cases}\lambda\cdot\dfrac{q}{1-q\left(r\bmod(1/q)\right)}, & n\in G\\ 0 & ,else\end{cases},$$

Where $\lambda=\dfrac{E\_node}{E_0}$, and E_node are the energy of the current node; E_0 is the node's initial energy; q is the percentage of cluster head node desired of all nodes; r is the current round number; G is the nodes muster which do not become a cluster head nodes in the final $1/q$ round .

3. Cluster formation

After cluster head is chosen, the network is organized into the breadth-first spanning tree topology, and the root node is based on time reference node. Each node has a jump distance variable level which arrive the time reference node, the level value of the only time reference node is 0, other nodes are infinite. According to the following two steps to establish topology: the first step, the time reference node sends packets of topology establishment, if the node received is the cluster head node, then the level is set to 1, otherwise, do not respond. The second step, the cluster head node sends packets of topology establishment to the ordinary node, for the node receiving packets of i layer, first, i is compared with itself level, if i is less than the level, their level will be set $i+1$, otherwise, it is discarded. The process is repeated until all nodes have been given the appropriate level. It is worth noting that if an ordinary node receives more than one nodes group, and it grade equals to its parent nodes, then compared with their power level, and selected the strongest power node as its parent node. After cluster head selection is completed and breadth-first spanning tree topology is established, the network is divided into multiple clusters and each cluster consists of a number of cluster member nodes and a cluster head.

C. Synchronization algorithm design

Considering the sources of the time synchronization error in the wireless sensor network, and in order to solve the problems that have large amount of information in general method of synchronization, a method based on an exchange of information is proposed, and maintain the entire cluster node synchronous by compensating each node for the cluster head node. After the cluster head nodes complete the synchronization in pairs to nodes in cluster, and time synchronization accuracy is maintained by making the cluster head node estimate the time to offset of each node. The system mainly analyzes the node synchronization process in the cluster, and takes the cluster head node as the third party node, that is, the synchronization for other nodes is completed by the cluster head node. In each synchronization cycle, synchronization process will be divided into two phases, the first stage is parameter estimation, it need to complete two tasks, namely, the initial synchronization of the node and the necessary parameters are estimated and stored by an exchange of information. The second stage is the time maintenance phase, after the initial synchronization is completed, the time clock of nodes in cluster is compensated regular or irregularly though the cluster head node. Compensation procedure is as follows.

(1) Complete time synchronization in pairs between each node in cluster and the cluster head node.

(2) The cluster head nodes send synchronization messages to each node.

(3) The cluster head node synchronization message is received by each node, each node sends the estimated values of the frequency offset to the cluster head, and send the local time at the same time.

(4) The cluster head nodes receive the message, and fill out the "time synchronization table."

(5) The cluster heads periodically calculate the time offset, and send to each node, each node corrects the time after receiving.

(6) Complete a synchronization cycle and repeat steps 1 to 5.

V. EXPERIMENT AND SIMULATION

A. Experimental verification

The nodes that we use are shown in Figure 7, the sensor nodes are placed in the greenhouse environment, in experiment, we selected three common nodes and a gateway node. Three common nodes are connected with the sensors, respectively. The gateway node is connected with computer together through the serial port.

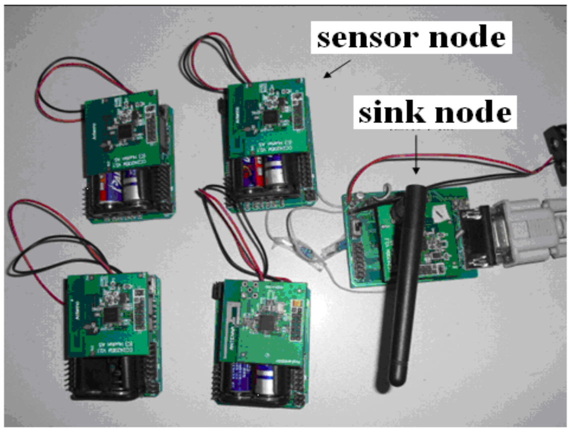


Figure.7 Physical map

In the system, we validates the feasibility of the system through data collection, and selects three nodes to make the data acquisition test of the 10 default temperature, set temperature is 8, 11, 12, 15, 18, 22, 23, 25, 27, 30, respectively, the test temperature data of each node is shown in Fig.8. By analyzing the measured temperature data, it shows that each sensor node respond better to temperature changes, and the sensor nodes only have some original error. The changes of humidity can be measured by the same method. The right collecting and transmitting of temperature and humidity data shows that the system is reliable and feasible.

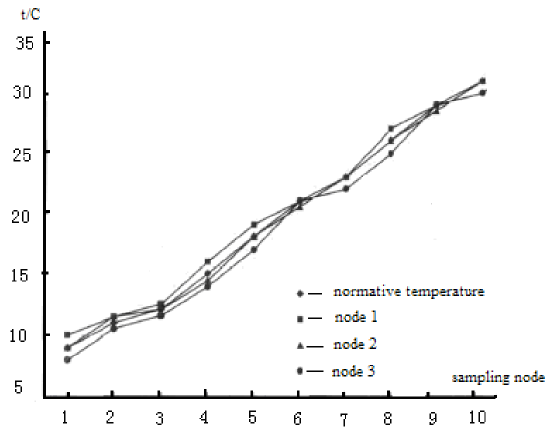


Figure.8 The test pattern of node temperature data

B. The simulation results and analysis

The synchronization algorithm that was proposed in the paper is evaluated by simulation tool NS2. First, the configuration of NS2 is as follows: Double diameter ground propagation model, gain omnidirectional antenna model, IEEE802.15.4MAC layer protocol and so on, and the module such as communication energy, the packet type, MAC timestamp type and track type and so on are modified, and Compared with TSPN algorithm, Set up the simulation environment to be the 50m×50m square area, we deployed 100, 120, 140, 160, 180, 200, 220, 240, 260 nodes, respectively, and the wireless communication distance is set as 10 m, the algorithm in the paper and TPSN algorithm are simulated respectively. The entire network adopt clustering algorithm to cluster. The simulation results are shown in Fig.9. Fig.9 show that the proposed algorithm requires much less synchronization overhead than TPSN, mainly because the cluster head node requires only one exchange of information in a synchronous cycle, thus it reduces overhead, the advantage is more obvious when the nodes are more.

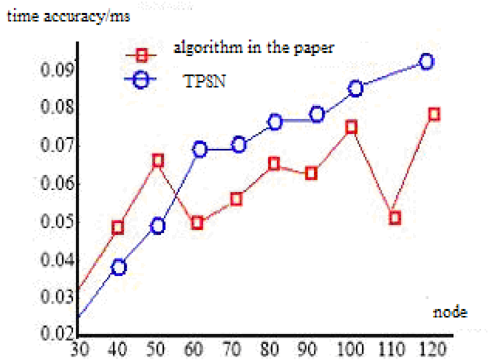


Figure 10 Compared with TPSN time accuracy chart

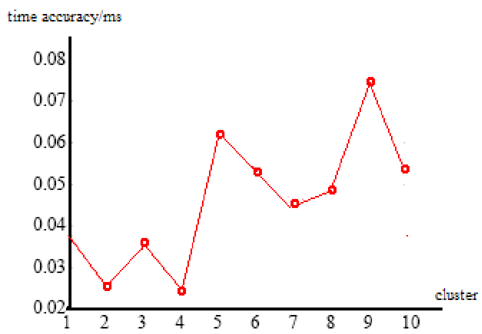


Figure.11 The average synchronization accuracy of each cluster

VI. CONCLUSION

According to the characteristics of the modern greenhouse production, the wireless sensor networks is applied to greenhouse measurement and control system in the paper, and combine wireless sensor network technology and greenhouse control technology to achieve automatic adjustment of the entire greenhouse system. In the hardware side, the wireless sensor network nodes mainly consist of control chip Atmega128L and wireless transceiver chip CC2530. In the software side, modular design thought is adopted, the deployment of sensor nodes is in-depth analyzed, and proposed a synchronization method based on time error compensation, achieved the synchronization in a certain error range by the few exchange of information. The synchronization efficiency are greatly improved, the node energy overhead is reduced. However, because the frequency deviation is estimated by the node, the time accuracy will be influenced by the frequency offset estimation, and the frequency offset estimate is researched the next step. From the simulation results, it can be seen that the algorithm is better than TPSN in energy costs and synchronization accuracy, so the system has a very good value.

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